Historical Perspectives on Atlantic Salmon *(Salmo Salar)* Enhancement Activities on Indian Brook, Newfoundland (1960-80) and Their Relevance with Respect to Community Involvement

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HISTORICAL PERSPECTIVES ON ATLANTIC SALMON (*SALMO SALAR*) ENHANCEMENT ACTIVITIES ON INDIAN BROOK, NEWFOUNDLAND (1960-80) AND THEIR RELEVANCE WITH RESPECT TO COMMUNITY INVOLVEMENT

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ABSTRACT

Pepper, V. A., and N. P. Oliver. 1986. Historical perspectives on Atlantic salmon (Salmo salar) enhancement activities on Indian Brook, Newfoundland (1960-80) and their relevance with respect to community involvement. Can. Tech. Rep. Fish. Aquat. Sci. 1461: iv + 66 p.

Historical data, on the Indian Brook Atlantic salmon stock, are examined to provide biological characteristics on which to determine the enhancement potential for this stock, its natural production potential in Indian Brook habitat, and the number of salmon that can be allocated in support of enhancement without jeopardizing natural production. Statistical parameters for these historical data are presented to provide a base from which to interpret future results of a new project to enhance this stock. This new salmon enhancement initiative, undertaken as a pilot project on lacustrine rearing of juvenile salmon, is described in an appendix that presents a 25-year plan for public involvement to enhance the Indian Brook salmon resource. This document characterizes the historical Indian Brook salmon stock and presents a plan for public involvement in management and development of this resource. The new enhancement plan separates operational aspects of the project (for public involvement) from the research components (for scientists and biologists). Formal interaction between the two components of the enhancement plan is used as a mechanism for more effective interpretation of scientific material to the concerned public and greater contact between resource biologists and users of these resources.

RÉSUMÉ

Pepper, V. A., and N. P. Oliver. 1986. Historical perspectives on Atlantic salmon (Salmo salar) enhancement activities on Indian Brook, Newfoundland (1960-80) and their relevance with respect to community involvement. Can. Tech. Rep. Fish. Aquat. Sci. 1461: iv + 66 p.

On examine les données antérieures concernant le stock de saumons de l'Atlantique du ruisseau Indian pour fournir des caractéristiques biologiques à partir desquelles on peut déterminer le potential de mise en valeur de ce stock, sa capacité de production naturelle dans l'habitat du ruisseau Indian et le nombre de saumons qui peut être alloué pour appuyer la mise en valeur sans compromettre la production naturelle. On présente des paramètres statistiques relativement à ces données pour fournir une base à partir de laquelle on puisse interpréter les résultats futurs d'un nouveau projet visant à mettre en valeur ce stock. Cette nouvelle initiative de mise en valeur du saumon, entreprise comme projet pilote sur l'élevage de jeunes saumons en milieu lacustre, est décrite dans une annexe qui présente un plan échelonné sur 25 ans relativement à la participation du public pour mettre en valeur la ressource en saumons du ruisseau Indian. Ce document caractérise le stock antérieur de saumon du ruisseau Indian et présente un plan pour la participation du public à la gestion et à la mise en valeur de cette ressource. Le nouveau plan de mise en valeur sépare les aspects opérationnels du projet (pour la participation du public) des éléments liés à la recherche (pour les scientifiques et les biologistes). L'interaction formelle entre les deux composantes du plan de mise en valeur est utilisée comme mécanisme pour permettre une interprétation plus efficace du matériel scientifique au public intéressé et pour un contact plus grand entre les biologistes des ressources et les utilisateurs de ces dernières.

INTRODUCTION

The varying fortunes of our Atlantic salmon resource are reflected in the size of the catch in our commercial and recreational salmon fisheries. While some variation in annual salmon production is normal, severe depressions in year-to-year salmon catches are symptoms of environmental or manmade stresses on the resource that arise from such diverse sources as weather, pollution, overfishing and illegal fishing, and habitat deterioration. Whatever the cause of depressed salmon production, salmon managers must respond, both to identify and to compensate for the problem. One approach to increasing salmon production is salmon enhancement. This involves the application of technology to overcome critical limitations in the salmon's life cycle, thereby supplementing natural production through colonization of new habitat and through improving the reproductive success of the species.

A variety of salmon enhancement methodologies have been applied in Newfoundland over the past 30 years. These methodologies have resulted in dramatic increases in some of our Atlantic salmon stocks. However, changing social, political, and economic values demand continuing reassessment of enhancement techniques to assure continuing efficiency of enhancement projects in terms of social and monetary benefits. This requires ongoing experimentation with new concepts in salmon enhancement and rigorous evaluation of these concepts through operation of carefully designed pilot projects. The latest project to be added to Newfoundland's developing enhancement plan is just such a pilot or demonstration project. Although considered primarily as a demonstration of new bio-engineering techniques for salmon enhancement, the Black Brook project is a pioneering endeavor to identify an optimum operating scenario for potential future salmon enhancement projects in Newfoundland.

The objective of this document is to outline biological considerations for maintaining natural salmon production while, at the same time, manipulating stocks to encourage increased production. In partial fulfillment of this objective, the present document seeks to gain a historical perspective on the biological characteristics of an Atlantic salmon stock (Indian Brook) to which publicly sponsored enhancement projects will be applied. This historical perspective will provide an objective base from which to document the results of these enhancement activities. The Black Brook, Atlantic salmon enhancement project is presented (Appendix 1) as the model for resource management and enhancement that incorporates public involvement in artificial and semi-natural propagation of Atlantic salmon.

PROJECT LOCATION AND HISTORY

Black Brook (49°27'N, 56°27'W) is a tributary of Indian Brook, Halls Bay, Newfoundland (Fig. 1). As the site for Newfoundland's first salmon production facility, Indian Brook has supported salmon fry stocking activities since 1963 when an artificial spawning channel first commenced operation (Pratt 1964). This enhancement project, terminated in 1975 due to budget cutbacks, was replaced by an experiment to investigate lacustrine stocking potential for swim-up salmon fry (Pepper et al. 1984). Results of these lacustrine stocking

experiments (Pepper et al. 1985a) have led to the present enhancement project centered on Black Brook.

The biological goal of the Black Brook project is to increase Atlantic salmon production within the Indian Brook watershed by an additional 20,000 adult salmon per year. This dictates that salmon brood be accumulated from the natural Indian Brook spawning escapement in support of artificial incubation requirements. This brood procurement must be controlled so as not to jeopardize present natural salmon production in the river. This document identifies the present and historical status of the Indian Brook salmon stock and considers spawning escapement required to maintain natural salmon production. This is used as the base for identifying the number of spawners potentially available in support of enhancement activities.

HABITAT CHARACTERISTICS AND ATLANTIC SALMON PRODUCTION POTENTIAL

Indian Brook drains a total of 1217 km^2 before discharging into Halls Bay, at the community of Springdale. Annual salmon runs to the brook have been enumerated at a fishway trap close to Halls Bay. These runs have ranged from 112 to 3072. Since most of the recreational fishery of this river is located at and below this fishway, fishway counts are considered representative of spawning escapement.

Indian Brook has several tributaries (Fig. 1). Most spawners utilize either the main river between the artificial spawning channel headwater dam and Indian Pond (a distance of 4.5 km), or the main river immediately below Indian Pond. To a lesser extent, the unobstructed portions of Black Brook (1.3 km), Shoal Pond Brook, and Burnt Berry Brook (1.4 km) also are utilized by salmon spawners. The amount and distribution of salmon spawning habitat for the Indian Brook watershed is identified in Table 1.

Historical natural spawner distribution in Indian Brook, as determined from spawning surveys and fishway counts of the number of fish in the river, indicates that there is considerable annual variation in spawner frequency in the various sections of the river (Table 2; $\chi^2 = 125.9$, $P < 0.0001$). On average, 50% utilize section 1, 37% utilize section 2, and 13% utilize section 4 (Table 2). The natural Indian Brook, Atlantic salmon escapement (i.e. salmon run to the river) has access to 3186 spawning units (1 unit = 100 m^2). Pratt and Sturge (1964) determined that each female grilse builds one redd on the average. Spawning behavior includes setting up a 'territory' of about 6 m^2 for each spawning pair. The male defends this area against intruders. On the basis of an average of 6 m^2 of accessible spawning habitat per female, currently accessible spawning habitat in Indian Brook requires a spawning population of 531 females.

It appears, from spawning surveys in Indian Brook, that redd 'overcutting' may take place in natural areas of ideal spawning conditions. In the context of historic Indian Brook salmon runs, it should be noted that, prior to 1979, average natural spawning escapement to Indian Brook was 567 (378 females; Table 3). In 1981 and 1982, when there were respectively approximately 2000 and 1500 females spawning naturally in the river, there was much spawner activity in the upper portion of section 2, near the Indian Brook spawning

channel. In fact, a scheduled spawning survey in this section was canceled due to the difficulty of completing the survey without walking on redds. Although quantitative data are not available, it appeared from observations made from the shore, that there was a significant incidence of redd superimposition. This would imply that habitat preferences of spawning salmon may not result in efficient utilization of spawning area, at least in situations where spawning populations are large and leads to speculation that, as the number of available spawners increases in Indian Brook, natural spawning area utilization efficiency (in terms of survival from egg to smolt) may be eroded. However, this speculation may be premature. Results of experiments conducted over the years at the Indian Brook spawning channel revealed that spawner density could be increased to one female per three square meters without serious consequence to egg survival (Pratt and Rietveld 1973). Pratt (1968) found that female salmon prefer to spawn immediately upstream of already established redds. Evidently the water flow pattern immediately upstream of an established redd is conducive to efficient deposition of eggs into the gravel and therefore Atlantic salmon often will spawn contiguous with existing redds without necessarily disturbing previously deposited eggs. Present evidence suggests that one female per three square meters of spawning habitat (i.e. total of 1062 female salmon) is a reasonable spawner density for Indian Brook.

SMOLT PRODUCTION POTENTIAL

The amount and distribution of juvenile salmon rearing habitat for Indian Brook also is identified in Table 1. In this table are two columns under the heading 'Rearing Units'. The second column appears because these spawning areas also are utilized by juvenile salmon as rearing habitat, even though this habitat potential is poor. Typical salmon spawning areas offer parr few hiding places, deep holes, or areas of slow water velocity. Collectively these habitat deficiencies become limiting, especially for larger parr. Electrofishing studies in these spawning habitats (Rietveld 1970) indicated predominantly Age 0+ parr with fewer Age 1+ parr. These studies indicated lower survivals, from the fry to pre-yearling parr stage, in spawning area than in rearing areas. They also demonstrated reduced survival from the Age 0+ to Age 1+ stages. Stomach analyses (Rietveld 1970) have shown considerable loss of Indian Brook salmon fry due to brook trout (Salvelinus fontinalis) predation. Sturge (1968) determined that spawning area is not well suited to the rearing requirements of salmon.

Rietveld (1970) indicated that differences between smolt production in 1967 (i.e. 3900), as contrasted with smolt production in 1968 and 1969 (i.e. 13,000 and 12,000 respectively), might be due to distribution of fry to good rearing areas. In 1964 and 1965, the numbers of spawning channel fry that were released were similar, yet resulting smolt productions varied considerably. Boulder/rubble habitats greatly outproduced gravel habitats. Spawning areas apparently are about 30% (3,900/12,000) as productive, in terms of numbers, as good rearing areas. Taking this into consideration, a spawning habitat productivity factor for parr rearing is calculated as 30%. This factor has been applied to the number of units of spawning habitat for each section of Indian Brook, then added to the number of rearing units in each of the respective river sections to produce an adjusted rearing habitat potential as in the second column under rearing units in Table 1.

Smolt production is expressed most commonly as numbers of smolts per unit of habitat. Table 4 identifies the range of smolt production calculated for some Newfoundland and Labrador rivers. If the estimates for Western Arm Brook are excluded from Table 4 (this brook is atypical due to its preponderance of standing waters), average smolt production per unit in Newfoundland is 1.7 and corresponds with the average of the two smolt production figures given for Indian Brook. Therefore, two smolts per unit is an optimistic production figure for Indian Brook. At this production level, accessible rearing area of Indian Brook (9,821 units) should be capable of producing approximately 20,000 smolts. Calculation of the actual number of spawners required to produce this many smolts is tenuous due to extremely variable salmon parr survival rates. Parr survival fluctuates from year to year and is dependent on such variables as climate, predator and competitor abundance, stocking density, previous year-class survival, and industrial activities. Table 5 identifies spawner requirements, based on observed ranges in egg-to-fry and fry-to-smolt survival rates, to meet a production of 2 smolt/100 m^2.

INDIAN BROOK, ATLANTIC SALMON STOCK CHARACTERISTICS

SPAWNERS

The Indian Brook, Atlantic salmon stock is composed primarily of grilse (one-sea-winter salmon). Larger salmon (multiple sea-winter) are rare. Monitoring of this stock since 1956 has indicated a grilse component of 91 to 100% (Moores and Ash 1984).

In most years, Atlantic salmon begin to enter the river in mid to late May. The recreational fishery on this river is confined to the period from the third week in June until late August. Salmon runs to the Indian Brook fishway usually continue through to late September. Peak migration to the river usually is during the third and fourth weeks of July.

During previous salmon enhancement activities on Indian Brook, salmon have been captured at the fishway, throughout the migration period, and transferred to the Indian Brook Spawning Channel (IBSC) to serve as brood stock. Size characteristics of brood stocks during the 1970s are presented in Table 6 and Fig. 2. Weight-length regression coefficients for the male and female data sets of Table 6 are homogeneous by year (minimum P = 0.0578). However, intercepts for these functions, with the exception of 1978, were significantly different (maximum P = 0.0142). Age distribution of these brood stocks is presented in Table 7. The incidence of repeat spawners at the IBSC has varied considerably from year to year (Table 7). From 1963 to 1980, the incidence of repeat spawners in the spawning channel brood stock has averaged 5.9%. Average return rate of kelt from this channel (i.e. kelt out in year Y: repeat spawners in year Y+1) is 5.5%. Sex ratio of the Indian Brook stock, as determined from brood stock at the spawning channel, has averaged 2.84:1::females:males (Table 8).

SMOLT

Smolt migration from Indian Brook starts in mid-May and continues until late June. Peak migration from riverine habitat usually takes place during the first week in June (Pond 1971). Size and age composition characteristics of Indian Brook smolt are identified in Tables 9 and 10.

PREVIOUS SALMON ENHANCEMENT ACTIVITIES

FRY STOCKING

Enhancement activities at Indian Brook from 1964 to 1975 were based on swim-up fry distribution to main stem stream habitat from the artificial spawning channel (Table 11). Regression of total river escapement (fishway count + angling catch) on number of fry distributed (adjusted for correspondence of year-class and spawning escapement) suggests there is no functional relation between these two variables ($F = 0.003$, $P = 0.999$). Since fry were distributed to different sections of the river in different years, it is possible that results of fry stocking differ with habitat characteristics. Approximately 56% of fry produced at the spawning channel in 1974 and 1975 were distributed to stream habitat of Black Brook during these last two years of the project. An increase in spawning escapement resulting from the 1975 fry year-class (i.e. 1979 spawning escapement) is evident (Table 3).

In previous Indian Brook fry stocking projects (Rietveld 1970), unfed salmon fry were stocked at a density of 22 per unit. Such fry distributions yielded an average fry to mid-summer survival of 50% in gravel and rubble habitat and 65% in rubble and boulder habitat. Sturge (1968) concluded that fry stocked at less than 100 per unit yielded higher fry survivals than those stocked at 400 per unit in his Indian Brook experiments. Pratt and Rietveld (1973) stocked fry at 35 per unit, 45 per unit and 70 per unit in the Exploits River, Newfoundland. They found that the 45 per unit stocking density resulted in the highest survival to the fingerling stage. Based on 20% natural egg-to-fry survival for Indian Brook, Sturge (1968) recommended 48 per unit. It appears that the optimum fry stocking density for Indian Brook may lie somewhere between 22 and 100 fry per unit and that habitat type is of major significance in determining optimum stocking density.

If a stocking density of 50 unfed fry per unit is applied to the 9821 accessible rearing units of Indian Brook, natural rearing habitat would support about 0.5 million fry. Table 12 identifies spawning requirements in support of this number of fry under various egg-to-fry survival regimes. It should be noted that a natural fry density of 50 per unit in Indian Brook would require an egg deposition approaching 500 per unit (i.e. assuming egg-to-fry survival of 10%). Such an egg deposition may be wasteful of brood potential.

The Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC) requirement of 240 eggs per unit of river habitat dictates a total annual egg deposition for accessible Indian Brook habitat of about 2.9 million eggs. On the basis of an average weight of 1.31 kg per female Indian Brook salmon, and 1800 eggs per kg, currently accessible habitat of Indian Brook requires a salmon brood of 1227 females. At a 2.84:1::female:male sex ratio, total spawner requirement is 1658 (Table 12). Assuming adequate distribution of spawning and rearing habitat, this spawner population would support self-sustaining salmon production for all but watershed sections 3 and 5 (Table 1).

APPRAISAL OF PREVIOUS ENHANCEMENT

The Indian Brook fishway was constructed in 1957 and operated for the first time in 1958. Records show that the maximum spawning escapement to Indian Brook, prior to operation of the spawning channel in 1963, occurred in 1958 when 923 fish (843 grilse and 80 salmon) were enumerated at the fishway. Average escapement to Indian Brook from 1958 to 1961 was 513. Fishway counts since that time have been increasing (Table 3). Five year running averages of fishway counts indicate that the ratio of offspring spawners to parent spawners increased three to four fold from 1963 to 1980 (Table 13). The greatest escapement to Indian Brook was in 1979 when 3072 fish (2959 grilse and 113 salmon) were released from the fishway. With increasing numbers of spawners in the river, the average amount of spawning area available per female is decreasing.

Increasing salmon counts at the Indian Brook fishway support the contention that salmon production for this river has been improving. To evaluate whether this increase may be attributed to enhancement activities, or might be simply a result of natural population increase, requires that Indian Brook salmon production indicators (i.e. fishway counts, angling catch and effort data) be compared with other rivers for which there are similar data.

Two other Newfoundland rivers to which enhancement activities have been applied are Torrent River and Terra Nova River. Fishways have been constructed on both of these rivers in support of habitat colonization above impassible falls (Farwell and Porter 1979). In addition to fishway construction, an adult transfer project was implemented at Torrent River in which salmon were collected from a nearby river and transferred to suitable Torrent River habitat. Since Terra Nova River enhancement was limited to fishway construction and did not receive any additional enhancement activity, the three rivers (Terra Nova, Torrent, and Indian: Table 3) represent an increasing progression in enhancement effort. If the return per unit of enhancement effort were consistent among these projects, one would expect an increasing rate of salmon population increase among these systems.

Total river escapements (fishway counts plus angled catch) are shown in Fig. 3. These escapements suggest that there may be a correspondence between the level of the enhancement activity and subsequent salmon production. Results of moving median calculations (Tukey 1977) for these river escapement data (to smooth some of the fluctuations in annual counts) are presented in Fig. 4. Progression towards higher production levels in Torrent River and Indian Brook is evident. Attempts at analysis of these trends using covariance (angling catch regressed on effort) failed due to different catch-effort relations ($F = 22.49$, $P = 0.0001$) among the three rivers. While not conclusive in an analytical sense, these catch-effort data (Table 14) suggest that enhancement benefits are directly related to the intensity of enhancement efforts. It is apparent that all of the three rivers subjected to enhancement activities showed increasing salmon production. However, we still have not demonstrated that increasing production is a result of enhancement. This requires evaluation of production in rivers for which stocks were not manipulated. For this perspective, we turn to two other rivers of the Halls Bay area: South Brook and West River.

Recreational fishery data for these two rivers (Table 15) suggest that production has been fluctuating but has not shown any substantial increase. Of considerable interest to these interpretations is the change in the five-year mean catch and C/E (catch per unit of effort) for all three Halls Bay rivers in the period 1978-82. This change cannot be attributed completely to changes in salmon production. In 1980, the commercial salmon fishery was changed so that effort was redistributed to areas outside of Halls Bay. Prosecution of the fishery thereby was diffused over a wider geographic area with the net result that more salmon escaped fishery exploitation. It is possible this change in management of the commercial salmon fishery may have contributed to the observed concurrent jump in angling catch in all three Halls Bay rivers. This factor, though it does not account for increased Indian Brook escapement in 1979, must be taken into account when evaluating the progression in Indian Brook salmon production relative to enhancement activities.

It is evident that the switch in stocking habitat, from Indian Brook to Black Brook, has corresponded with increased river escapement. However, recalling that 1980 was the year in which the Halls Bay fishery was changed, it still is questionable whether observed increases in river escapement are due to enhancement or management practices. This uncertainty is resolved in part by reconsideration of Table 15. Average angling C/E from 1980 to 1985 is 0.47 for South Brook and 0.50 for West River. These same data for the five years previous to 1980 (i.e. 1975-79) are 0.40 and 0.37 respectively. Thus, average angling C/E in South Brook from 1980 to 1985 is 1.2X (0.47/0.40) of the catch in the five years prior to this time. Corresponding data for West River indicate a 1.4X increase (0.50/0.37). Averaging these two values suggests that Halls Bay river salmon escapements increased approximately 1.3X in this interval. Considering the change in the commercial fishery in 1980, it is possible that this 30% increase in salmon escapement to Halls Bay rivers may have been due to management practices alone. Prior to 1980, total salmon escapement to Indian Brook averaged 1462. Compared with an average post-1979 river escapement of 3000 (Table 3), Indian Brook salmon increased 3.2X in number. This is considerably higher than the 1.3X average increase calculated for the other Halls Bay rivers. We interpret that about 60% (i.e. 1.0-1.3/3.2) of the average increase in Indian Brook salmon production, as indicated by increasing river escapements, is due to enhancement activities and that effects of these enhancement activities have been highly dependent on the habitats to which fry have been distributed. Efficiency of fry distribution (as measured by fry-to-adult survival) to main stem habitat has been much lower than for distributions to Black Brook habitat as suggested by increased 1979 escapement.

Increasing fishway counts represent the most obvious change in the Indian Brook salmon stock during the interval in which salmon enhancement activities have been applied to the river. On the basis of an average spawning escapement to Indian Brook since 1980 of 2275 (Table 3), and calculations as per Pepper et al. (1985a), it appears that present production of salmon from Indian Brook, before fishery exploitation, is in the range of 7000 to 8000 grilse annually. Increasing grilse:salmon ratios are coincident with increased spawning escapement (Table 7). Grilse:salmon ratios from 1958 to 1980 have risen from 10:1 to as high as 70:1 suggesting that the two-sea-winter component of the stock has been all but lost. Weight-length regressions of brood stock used at

the Indian Brook spawning channel suggest a progression towards decreasing weight per unit of length (i.e. slopes of Table 6). This progression, together with the incidence of net marks on a high proportion of brood specimens (usually > 50%) suggests a heavy selection pressure by the commercial salmon fishery mediated by gillnet mesh (minimum of 127 mm) regulations. This fishery is effective in removing large salmon from the stock, thereby progressively reducing this component of the genotype. Significant changes in fishing techniques would have to be imposed on the fishery in order to reverse this trend toward an increasingly grilse stock. Possibilities for motivating such a shift in stock characteristics include terminal or river harvest in which harvest would exclude brood characteristics required for selective breeding programs.

DISCUSSION

It is important, in planning and operating salmon enhancement projects, to assure that projects are managed to obtain production benefits. Results of enhancement projects often are highly variable and if projects are not monitored carefully, they may fail to meet production goals thereby risking early termination of the project. Much has been learned about potential efficiencies of a variety of enhancement methodologies over the past 30 years of enhancement activity in Newfoundland. Research relative to development of accurate models for predicting enhancement benefits is expected to continue. In all of these enhancement initiatives, the ultimate biological goal is to maximize salmon production (while minimizing negative impacts on other freshwater fish species) at the same time as minimizing costs necessary to support such production. Historic Indian Brook activities have shown that habitat characteristics are important to salmon production and that production efficiencies vary considerably among habitats. This process of identifying limitations to salmon production is the main mechanism by which new enhancement technologies are developed in support of improved efficiency of project operation. As is often the case, there is a problem that has been stated aptly in popular science fiction:

> "The assumption that a whole system can be made to work better through an assault on its conscious elements betrays a dangerous ignorance . . ." (Herbert 1976).

In planning any Atlantic salmon enhancement project, it is necessary to determine if the system and project in question has significant additional production potential. This requires biobaseline 'inventory' surveys to determine both present production and production potential (Pepper et al. 1984). If a river system is producing to capacity, it should be considered as a management responsibility and not as an enhancement opportunity. Assuming that salmon enhancement activities are justified, project planners must address a variety of ecological concerns including protection of the existing resource, monitoring interacting resources (i.e. salmon and trout interactions) and ecosystem stability. As implied by Herbert in the above quote, systems interact as an integrated complex of subunits and manipulation of these subunits may have unforeseen consequences on the system as a whole. While the immediate goal of salmon enhancement is improved salmon abundance, the larger

concern is for long-term stability of production. Salmon enhancement requires working (and interfering) with ecological systems.

> "Ecology . . . is basically directed at working with nature, determining the course of natural systems, phenomena and laws, and compromising the desires and needs of man with the course of nature as far as is reasonable and feasible." (White-Stevens 1976)

Where application of technology for increasing salmon production is both reasonable and feasible (proven technologies supporting cost-effective, long-term increases in salmon production in stable ecosystems), salmon enhancement can be a valuable mechanism for fostering social and economic benefits. Such goals are compatible with the concept of private, non-profit hatcheries (Orth 1977).

The private, non-profit hatchery is a concept developed in the Pacific north-west wherein user groups may contribute to the common property resource by operating salmon hatcheries. In exchange for this contribution, these hatchery operations are allowed to harvest salmon that return to the hatchery. In such situations, government maintains strict control over hatchery location so that hatchery operation does not interfere with management and harvest of the stock(s) supported by the hatchery enterprise. Potential economic viability has been demonstrated for these common property enhancement facilities (Orth 1977). The private, non-profit hatchery therefore provides employment opportunities for rural communities at the same time as supporting traditional fisheries through enhanced salmon production. While this sort of enterprise, with its corresponding terminal harvest as a means of recovering operating costs, is not possible in Canada under present legislation, many of the concepts on which the non-profit hatchery is based are similar to the rationale on which the present Indian Brook/Black Brook enhancement plan is structured.

INDIAN BROOK ENHANCEMENT

During three decades, Indian Brook, Atlantic salmon enhancement activities have attempted to identify and overcome the biological constraints that apply to the watershed. With a main stem composed primarily of spawning habitat, and tributary habitat that is better suited to parr rearing, the Indian Brook system has natural habitat distribution that is not compatible with Atlantic salmon life history. The discontinuity of natural spawning and rearing habitats implies that Indian Brook salmon either will spawn in good habitat that is not conducive to later parr rearing, or that the salmon must spawn in poor habitat in which parr (if any survive the incubation phase) will have good rearing conditions. Either situation implies suboptimal salmon production that indicates the desirability of applying salmon enhancement technology. Throughout the early history of Indian Brook enhancement activities, the preferred development option was swim-up fry distribution from a controlled flow spawning channel. Of course, one of the first issues to be addressed was how many fry should be distributed per unit of habitat and what types of habitat would convey the greatest survival and growth advantage. Optimum

stocking density per unit of suitable rearing habitat still is one of the first questions to be addressed in any new enhancement project.

O'Connell et al. (1983) pointed out that there is considerable uncertainty in the literature as to what constitutes an optimal egg deposition rate or optimal fry stocking density. Kennedy (1982) stated that, due to differences in climate, water quality, densities of competing fish species, and depth and flow regimes, it would be inappropriate to apply optimum stocking densities from one river system to another. For these reasons, production rates of other rivers of Newfoundland and the Maritime Provinces are useful only to identify tentative ranges in production potentials. Symons (1979) suggested that optimal production for Age 3+ smolts would be obtained by an egg deposition rate of 165-220 per unit. Elson (1957a, 1975) recommended egg deposition rates of 168 per unit for the Miramichi River and 240 per unit for the Pollett River, New Brunswick. Elson's (1957a) figure for optimal egg deposition (240 eggs per unit) equates to 24, 36 and 48 fry per unit respectively using tentative egg-to-fry survivals of 10, 15 and 20%. This egg deposition figure is used widely in Eastern Canada and now has been adopted by the CAFSAC. Chadwick (1982) concluded that egg deposition could be considerably higher than 240 eggs per unit in many rivers due to parr rearing in standing waters. Pepper et al. (1985b) have provided evidence that significant numbers of juvenile salmon utilize ponds as nursery areas in some situations. Based on observations of Pepper et al. (1985b), juvenile salmon rearing potential (0.17 $kg \cdot ha^{-1}$) of the only accessible body of standing water in Indian Brook (Indian Pond) could be met by 36-72 grilse (1-sea-winter salmon). This consideration of standing water habitat potential for Indian Brook, together with calculations of smolt carrying capacity (Table 5) indicates that a total of 323-1218 brood salmon is required to maintain optimum natural production of the Indian Brook salmon stock. On the basis of CAFSAC recommendations (240 eggs per unit), 1658 brood salmon are required (Table 12). Considering potential spawner interference and superimposition of redds at high spawner densities (such as 1981 and 1982) and the discontinuity of natural Indian Brook spawning and rearing habitats, Indian Brook spawning escapement should be limited to approximately 1400 grilse (i.e. one female/three m^2 spawning habitat) to maintain the status of the existing stock.

It is apparent from the upward progression in the ratio of offspring spawners to parent spawners (Table 13), that the efficiency of salmon production in the Indian Brook system is improving. During the interval of 1976 to 1980, this measure of spawner efficiency averaged 2.46 as contrasted with 1.63 for the period prior to 1976. There is an average production advantage of at least 1.5X for enhancement activity as compared with natural production. There is a 3.8X improvement in brood reproduction efficiency from the beginning of Indian Brook enhancement activities to 1980. Therefore, it is likely that, for every brood salmon extracted from the Indian Brook stock in support of additional enhancement activities, as many as three salmon may return. In a social and economic context, this clearly is superior to the historical natural situation of one salmon back to the river to spawn for every individual of the previous parent generation.

The Black Brook tributary of Indian Brook now supports a community involvement project for salmon enhancement. This project is supported by

considerable technical coordination, both in the form of on-site advice and in the form of a long-term operating plan (Appendix 1). This means of technology transfer to the interested public is particularly attractive to rural settings where formal education opportunities, in renewable resource management, often are nonexistent. Present experience is indicating that, in the presence of a competent project manager, on-the-job training is sufficient to provide the necessary skills for day-to-day operation of salmon enhancement projects. However, the technical acumen to provide an objective assessment of project results (Appendix 2) may have to come from the resource manager. The present report attempts to provide an objective base from which to evaluate the future results of the Black Brook, Atlantic salmon enhancement project.

Implementation of a salmon enhancement project, so as to increase salmon production without jeopardizing natural stocks, requires identification of a salmon brood source that is surplus to the natural spawning requirements of the river system to which the enhancement project is to be applied. This in turn requires knowledge of the present status of the salmon stock and of natural production potential within the system, together with evaluations of the factors that are limiting salmon production (i.e. amount of spawning habitat, rearing habitat, competing species, pollution, etc.). Salmon enhancement projects can be implemented only after consideration of these factors has identified the scope of the project.

For Indian Brook, the potential scope of salmon production has been evaluated by Pepper et al. (1984). On the basis of expected survival rates and historic Indian Brook stock characteristics, Indian Brook salmon enhancement activities could result in a spawner to parent spawner ratio of almost 5:1 (Table 16). There is a significant amount of habitat within the Indian Brook watershed that currently is not accessible to salmon and therefore does not support natural salmon production. This habitat can be brought into production through application of low technology enhancement techniques that are potentially cost effective (Pepper et al. 1984).

Having once identified a salmon enhancement project as desirable in an economic sense, one of the first responsibilities in project implementation is protection of the existing natural population. It is only after identifying the number of salmon spawners required to support natural production and the present size of the spawning escapement, that it is possible to determine the number of brood fish that can be made available to the enhancement project.

This report has presented evidence that natural Atlantic salmon production in Indian Brook requires an annual spawning population of approximately 1100-1500 and contends that escapement in excess of 1400 should be applied as brood in support of enhanced production. By providing a historical perspective on Indian Brook stock characteristics, we have provided an objective base from which to measure any future shifts in stock phenotype and production level. Such interpretations of future stock characteristics will be important to assure that the enhancement project will meet its social, biological and economic requirements and, in so doing, generate continued support by funding agencies and enthusiasm among project sponsors and user groups alike.

The data presented are examples of some of the biological considerations that must be impressed on public groups to avoid ". . . a dangerous ignorance", and thereby encourage continuing public support for the principles of conservation and resource management that are the means by which the varying fortunes of our Atlantic salmon resource will be stabilized at optimum production levels to the benefit of our commercial and recreational salmon fisheries.

SUMMARY

1) Based on the amount of Indian Brook and tributary habitat that is accessible to adult salmon at the present time, salmon production potential for this watershed is 20,000 smolts. At an average smolt-to-adult survival rate of 10%, this equates to 2000 adults per year. Currently inaccessible habitat upstream of the spawning channel headwater dam has the potential to produce 3000 smolts (i.e. 300 adults) per year.

2) Present production of salmon from Indian Brook habitat, based on average spawning escapement from 1980 to 1983, is 6000 to 7000 adults per year. It appears that present salmon production from Indian Brook habitat is exceeding expectations of production potential.

3) Spawning escapement required to support natural salmon production potential of accessible habitat of Indian Brook is approximately 1100 to 1500 adults. Spawning escapement to natural habitat that exceeds this level may increase spawner interference in areas of prime spawning habitat.

4) Spawner success, as indexed by the ratio of offspring spawners:parent spawners, has been increasing since the beginning of enhancement activities in 1963. Data suggest that, on the average, each spawner now produces about three offspring adults as contrasted with about one offspring adult in the early history of the enhancement project.

5) Management practices alone may have resulted in a stock production increase of about 30%. Increased production due to enhancement activities has been about 90%.

6) Results from enhancement activities have varied greatly with the types of habitat stocked. Rearing potential, of typical spawning habitat, is only about 30% that of rubble-boulder rearing areas.

7) The Indian Brook stock is predominantly grilse. Grilse:salmon ratios have increased from 10:1 in 1958 to 26:1 in 1979. Smolt ages for the riverine population have averaged 16% Age 2, 69% Age 3 and 13% Age 4. On average, repeat spawners account for 5.5% of the brood stock. Brood weight-length regressions have varied considerably among years. Spawning escapement has averaged 74% female.

8) Additional salmon production, from an expanded Indian Brook enhancement project to stock currently inaccessible lacustrine habitat of Black Brook, is expected to triple present production.

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Table 1. Habitat characteristics of Indian Brook watershed

Section	Location	Rearing Units[a] A	Rearing Units[a] B[b]	Spawning
1	Indian Pond to mouth	7888	8604	2388
2	Spawning Channel dam to Indian Pond	467	686	729
3	Spawning Channel dam to diversion	1149	1473	1081
4	Accessible area of Black Brook	510	531	69
5	Above Black Brook Falls	6376	6381	16
	Totals	16390	17675	4283
	Totals (accessible at present)	8865	9821	3186

[a] 1 unit = 100 m^2.

[b] B = A + (spawning units x 0.3). See text.

Table 2. Spawning surveys of Indian Brook watershed.

Year	Total redds	% of total redd count: Section 1 — Indian Pond to smolt weir	Section 1 — Below smolt weir	Section 2 — IBSC[a] to Indian Pond	Section 4[b] — Black Brook
1968	223	60/223 = 26.9%	40/223 = 17.9%	115/223 = 51.57%	8/223 = 3.6%
1970	226	40/226 = 17.7%	50/226 = 22.1%	66/226 = 29.2%	70/226 = 30.98%
1971	107	28/107 = 26.2%	31/107 = 28.97%	37/107 = 34.6%	11/107 = 10.3%
1973	254	105/254 = 41.34%	49/254 = 19.29%	83/254 = 32.68%	17/254 = 6.7%
Total	810	233/810 = 28.77%	170/810 = 20.99%	301/810 = 37.16%	106/810 = 13.09

[a]Indian Brook spawning channel.

[b]Section 3 is the main stream area between the IBSC headwater dam and the upper watershed diversion structure. Natural spawner distribution is limited to areas downstream of the IBSC dam. Therefore Section 3 is not included in this table.

Table 3. Atlantic salmon escapement to rivers supporting different levels of enhancement activity.

	Indian Brook			Lower Terra Nova River			Torrent		
Year	Escapement	Angled	Total	Escapement	Angled	Total	Escapement	Angled	Total
1958	923	429	1352	872	135	1007			
1959	456	281	737	461	140	601			
1960	519	180	699	707	165	872			
1961	154	177	331	417	131	548			
1962									
1963	289	224	513	871	303	1174			
1964	1244	575	1819	716	339	1055			
1965	394	258	652	728	337	1065			
1966	295	257	552	558	226	814	40	56	96
1967	116	127	243	972	339	1311	51	47	98
1968	682	351	1033	1089	331	1420	30	77	107
1969	225	155	380	1051	523	1574	23	45	68
1970	392	191	583	1224	461	1685	38	61	99
1971	364	267	631	857	413	1270	55	58	113
1972	112	102	214	957	478	1435	60	25	85
1973	717	374	1091	754	335	1089	107	91	198
1974	624	147	771	450	248	698	41	62	103
1975	799	101	900	1390	508	1898	216	129	345
1976	356	143	499	609	431	1040	388	0	388
1977	1330	503	1833	1006	863	1869	822	0	822
1978	1138	278	1416	830	634	1464	989	35	1024
1979	3072	437	3509	739	552	1291	2023	68	2091
1980	1785	544	2329	882	534	1416	849	0	849
1981	2847	884	3731	1205	772	1977	2199	185	2384
1982	2216	754	2970	983	489	1472	2635	83	2718
1983	2253	538	2971	1267	529	1796			

Table 4. Smolt production per unit (100 m^2) of habitat for Newfoundland and Labrador Rivers.

River	Mean annual smolt production	Reference
Little Codroy River	2.57	Murray 1968
North Habour River	0.96	Lear & Day 1977
Western Arm Brook	9.66[a]	Chadwick 1981
Sand Hill River '69	1.80	Pratt, Hare & Murphy 1974
Sand Hill River '70	1.70	Pratt, Hare & Murphy 1974
Sand Hill River '71	1.80	Pratt, Hare & Murphy 1974
Sand Hill River '72	1.20	Pratt, Hare & Murphy 1974
Sand Hill River '73	1.60	Pratt, Hare & Murphy 1974
Indian Brook	1.50	Riche 1972
Indian River '69	1.90	Pratt, Farwell & Reitveld 1974
Salmon Brook	2.00	Riche 1972
Exploits River '67	1.50	Farwell 1975
Exploits River '68	1.90	Farwell 1975

[a]A large area of standing waters and smaller tributaries has been included in these figures. Therefore the production figure does not represent classical rearing area production.

Table 5. Indian Brook brood requirements for Altantic salmon based on accessible habitat carrying capacity of 20000 smolt.

Fry requirements at fry-to-smolt survival rates of:

10%	15%	20%
200 000	133 000	100 000

Egg requirements (in millions) at egg-to-fry survival rates of:

10%	15%	20%	10%	15%	20%	10%	15%	20%
2.0	1.3	1.0	1.3	0.9	0.7	1.0	0.7	0.5

Female brood required[a] to fulfill egg depositions.

848	566	424	566	377	283	424	282	212

Total spawner requirements[b] to fulfill egg depositions.

1146	765	576	765	510	382	573	382	287

[a]Mean weight per female = 1.31 kg.
Mean fecundity = 1800 eggs/kg.

[b]Sex ratio = 2.84:1::female:male (i.e. 73.96% female).

Table 6. Atlantic salmon brood weight-length regression statistics for Indian Brook brood stocks, 1970-78.

Year	Sex	Regression parameters		Mean[a] length	Mean[a] weight	Adjusted[b] mean weight	N
		Intercept	Slope				
1970	Male	-14.3782	3.4423	504.9	1150.3	1094.7	94
	Female	-12.8055	3.1932	494.6	1101.9	1120.7	276
1974	Male	-7.4765	2.3464	508.9	1269.9	1196.2	77
	Female	-8.1027	2.4530	493.1	1221.4	1242.0	275
1976	Male	-10.2066	2.7824	523.4	1356.0	1291.0	49
	Female	-9.4239	2.6671	511.3	1353.5	1372.7	171
1977	Male	-12.3116	3.1155	505.6	1194.1	1153.6	47
	Female	-9.5779	2.6821	497.9	1186.5	1196.8	187
1978	Male	-8.7082	2.5417	511.9	1270.2	1215.4	54
	Female[c]	-9.3985	2.6565	500.6	1228.7	1246.4	166

[a]Means calculated from log transformed regression parameters.

[b]Calculated from regression equations.

[c]Mean weight of females for all five years combined is 1204 g.

Table 7. Indian Brook spawning channel brood stock age distribution and spawner history.

Year	Sample size	% grilse	% grilse previous spawners	% salmon	% salmon previous spawners	Age						
						3_2[a]	4_2	4_3	5_3	5_4	6_3	6_4
1963	43	100.0	20.9	0.0	0.0							
1964	136	100.0	0.0	0.0	0.0							
1965	94	100.0	4.3	0.0	0.0							
1966	161	88.2	3.7	11.8	0.6							
1967	93	92.5	6.5	7.5	1.1							
1968	229	92.1	0.0	7.9	0.4							
1969	130	93.8	9.2	6.2	0.8							
1970	185	93.5	0.0	6.5	0.0							
1971	150	97.3	0.0	2.7	0.0							
1972												
1973												
1974	351	100.0	0.0	0.0	0.0							
1975												
1976	220	99.1	19.6	0.9	0.0			138	44	30		8
1977	234	100.0	7.3	0.0	0.0	15		171	14	31	1	2
1978	225	100.0	16.9	0.0	0.0	1	3	183	35	3		
1979												
1980	125	100.0	0.0	0.0	0.0	6		116		3		

[a]Line numeral represents total age. Subscript is number of years spent in fresh water.

Table 8. Sex ratio of brood stock from Indian Brook spawning channel.

Year	Total broodstock	# males	# females	Average weight of females (kg)	Sex ratio (female:male)
1963	112	36	76	1.361	2.11:1
1964	283	82	201	1.451	2.45:1
1965	142	32	110	1.389	3.44:1
1966	146	32	114	1.315	3.56:1
1967	156	66	90	1.406	1.36:1
1968	312	72	240	1.360	3.33:1
1969	144	52	92	1.211	1.77:1
1970	195	48	147	1.111	3.06:1
1971	335	81	254	1.166	3.14:1
1972	82	26	56	1.093	2.15:1
1973	403	105	298	1.312	2.84:1
1974	400	103	297	1.251	2.88:1
1975	-	-	-	-	-
1976	218	49	169	1.370	3.45:1
1977	234	47	187	1.380	3.98:1
1978	251	57	194	1.390	2.40:1
1979	-	-	-	-	-
1980	-	-	-	-	-
Cumulative summary		888	2525	1.309	2.84:1

Table 9. Indian Brook Atlantic salmon smolt age distribution.

Year	Sample size (N)	Age composition (expressed as % of sample and as actual numbers) 2+	3+	4+	5+
1966	149	23.6 (35)	64.6 (96)	7.6 (12)	0.7 (1)
1967	82	30.5 (25)	67.8 (56)	1.2 (1)	0 (0)
1968	108	20.4 (22)	78.7 (85)	0.9 (1)	0 (0)
1969	190	10.5 (20)	68.4 (130)	02.0 (38)	1.1 (2)
1970	96	2.1 (2)	88.5 (85)	8.3 (8)	1.0 (1)
1971	59	0 (0)	91.5 (54)	8.5 (5)	0 (0)
1972	99	0 (0)	87.9 (87)	12.1 (12)	0 (0)
1973	286	1.4 (4)	70.3 (201)	28.3 (81)	0 (0)
1979	109	98.2 (107)	0.9 (1)	0.9 (1)	0 (0)

Table 10. Indian Brook Atlantic salmon smolt, length and weight at age.

	Freshwater age												Overall yearly means		
	2+			3+			4+			5+					
Year	N	Mean length (cm)	Mean weight (g)	N	Mean length (cm)	Mean weight (g)	N	Mean length (cm)	Mean weight (g)	N	Mean length (cm)	Mean weight (g)	N	Mean length (cm)	Mean weight (g)
1967	25	12.15	20.05	56	14.54	32.48	1	17.80	54.60	0	-	-	82	13.85	28.96
1968	19	14.05	26.84	61	14.45	29.34	20	14.75	30.30	1	15.60	36.0	101	14.45	29.13
1969	20	13.34	-	130	14.67	-	38	15.59	-	2	16.85	-	190	14.74	-
1970	2	13.65	-	85	14.94	-	8	16.68	-	1	15.70	-	96	15.07	-
1971	0	-	-	54	15.05	33.11	5	16.86	44.16	0	-	-	59	15.20	34.08
1972	0	-	-	87	16.15	40.63	12	18.03	51.33	0	-	-	99	16.38	41.93
1973	4	14.48	32.60	201	15.90	37.19	81	17.19	46.22	0	-	-	286	16.25	39.68
Mean (1967-73)	70	13.38	23.78	674	15.26	35.74	165	16.56	44.04	4	16.25	36.0	913	15.34	36.41

Table 11. Indian Brook, Atlantic salmon fry distribution from spawning channel.

Year	Diversion to Channel			Channel to Indian Pond			Indian Pond to Main Fence			Black Brook			Total distributed
	No. fry distributed	No. units stocked	Fry/ unit	No. fry distributed	No. units stocked	Fry/ unit	No. fry distributed	No. units stocked	Fry/ unit	No. fry distributed	No. units stocked	Fry/ unit	
1964				44011	778	57							44011
1965	37875	588	64	94640	778	124	26000	1213	21				158515
1966	11381	657	17	130456	778	168							141837
1967	10065	104	97	9943	778	13	67112	1213	55				87120
1968	9000	104	87	4451	86	51	45658	2881	16				59109
1969				18331	778	24	149486	3640	41				167817
1970							27898	1062	26				27898
1971							167378	3943	42				167378
1972							54584	3640	15				54584
1973							69715	3640	19				69715
1974							128065	4398	29	174250	6813	26	302315
1975							149123	4398	34	182807	6813	27	331930
Sub-total	68321	1453	47.02	301832	3946	75.91	885019	30028	29.47	357057	13626	26.20	1,612,229

Table 12. Estimates of Indian Brook, Atlantic salmon brood requirements in support of natural riverine production potential based on literature recommendations for egg deposition and fry stocking.

Requirements	Fry stocking at 50 fry per 100 m^2			Egg depositions based on 240 eggs per 100 m^2
Total fry ($\times 10^6$)		0.5		
Egg-to-fry survival	10%	15%	20%	
Totals eggs ($\times 10^6$)	5.0	3.3	2.5	2.9
Female brood	2120	1413	1060	1227
Total brood	2867	1911	1434	1658

Table 13. Indian Brook, Atlantic salmon brood efficiency (offspring spawners: parent spawners).

Parent generation			Offspring generation		
Year	Spawning escapement	Moving[a] average	Year	Moving average	Ratio[b]
1963	289				
1964	1244				
1965	394				
1966	295				
1967	116	467.6	1972	355.0	0.76
1968	682	546.2	1973	362.0	0.66
1969	225	342.4	1974	441.8	1.29
1970	392	342.0	1975	523.2	1.53
1971	364	355.8	1976	521.6	1.47
1972	112	355.0	1977	765.2	2.16
1973	717	362.0	1978	849.4	2.35
1974	624	441.8	1979	1339.0	3.03
1975	799	523.2	1980	1536.3	2.94
1976	356	521.6			
1977	1330	765.2			
1978	1138	849.4			
1979	3072	1339.0			
1980	1785	1536.2			

[a]Moving averages calculated as per Tukey (1977).

[b]Calculated 5-yr average of offspring spawners:parent spawners.

Table 14. Recreational fishing catch and effort data for Torrent River and Terra Nova River.

Year	Torrent River			Terra Nova River		
	Angling catch	Rod days	C/E	Angling catch	Rod days	C/E
1953	13	169	0.08	164	1706	0.10
1954	18	187	0.10	85	1003	0.08
1955	37	184	0.20	194	335	0.58
1956	80	464	0.17	216	2685	0.08
1957	94	377	0.25	76	569	0.13
1958	58	594	0.10	135	590	0.23
1959	85	585	0.15	140	959	0.15
1960	86	401	0.21	165	463	0.36
1961	80	569	0.14	131	623	0.21
1962	144	893	0.16	279	777	0.36
1963	171	1286	0.13	303	1160	0.26
1964	106	593	0.18	339	699	0.48
1965	98	455	0.22	337	787	0.43
1966	56	794	0.07	226	117	1.93
1967	47	598	0.08	339	557	0.61
1968	77	998	0.08	331	143	2.31
1969	45	315	0.14	523	1477	0.35
1970	61	277	0.22	461	285	1.62
1971	58	333	0.17	413	1458	0.28
1972	25	306	0.08	478	456	1.05
1973	91	413	0.22	335	1044	0.32
1974	62	400	0.15	248	2098	0.12
1975	129	364	0.35	508	1723	0.29
1976	-	-	-	431	1236	0.35
1977	-	-	-	863	1956	0.44
1978	35	183	0.19	634	1608	0.39
1979	68	238	0.29	552	910	0.61
1980	-	-	-	534	872	0.61
1981	185	656	0.28	772	1303	0.59
1982	189	535	0.35	489	1174	0.42
1983	83	354	0.23	529	2157	0.25
1984	-	-	-	636	2042	0.31

Table 15. Recreational fishing, catch and effort data for Torrent River and Terra Nova River.

Year	Indian Brook			South Brook			Riverhead Brook (West River)		
	Catch angled	Rod days	C/E	Salmon angled	Rod days	C/E	Salmon angled	Rod days	C/E
1953	182	640	0.28	187	552	0.34	140	624	0.22
1954				115	203	0.57	186	490	0.38
1955	221	499	0.44	138	199	0.69	232	519	0.45
1956	313	513	0.61	153	268	0.57	472	769	0.61
1957	350	515	0.68	32	137	0.23	235	1187	0.20
5-year averages	267	543	0.49	125	272	0.46	253	718	0.35
1958	429	601	0.71	85	136	0.63	386	193	2.00
1959	281	516	0.54	51	173	0.29	166	743	0.22
1960	180	565	0.32	67	224	0.30	89	250	0.36
1961	177	478	0.37	19	98	0.19	35	187	0.19
1962	366	617	0.59	96	143	0.67	218	309	0.71
5-year averages	287	555	0.52	64	155	0.41	179	336	0.53
1963	224	601	0.37	191	204	0.94	265	340	0.78
1964	575	646	0.89	135	226	0.60	303	403	0.75
1965	258	729	0.35	224	293	0.76	329	568	0.58
1966	257	616	0.42	142	392	0.36	520	826	0.63
1967	127	520	0.24	68	275	0.25	161	541	0.30
5-year averages	288	622	0.46	152	278	0.55	316	536	0.59
1968	351	622	0.56	207	233	0.89	567	779	0.73
1969	155	534	0.29	81	245	0.33	308	707	0.44
1970	191	482	0.40	248	554	0.45	600	1121	0.54
1971	267	555	0.48	218	398	0.55	416	877	0.47
1972	102	390	0.26	82	176	0.47	189	429	0.44
5-year averages	213	517	0.41	167	321	0.52	416	783	0.53
1973	374	720	0.52	314	605	0.52	554	795	0.70
1974	147	570	0.26	108	845	0.13	166	816	0.20
1975	101	396	0.26	152	657	0.23	195	626	0.31
1976	143	584	0.24	175	535	0.33	298	1015	0.29
1977	503	1199	0.42	191	487	0.39	367	927	0.40
5-year averages	254	694	0.37	188	626	0.30	316	836	0.38

Table 15 (cont'd)

Year	Indian Brook			South Brook			Riverhead Brook (West River)		
	Catch angled	Rod days	C/E	Salmon angled	Rod days	C/E	Salmon angled	Rod days	C/E
1978	278	719	0.39	196	372	0.53	256	703	0.36
1979	437	973	0.45	245	368	0.67	382	731	0.52
1980	544	1168	0.47	349	657	0.53	745	937	0.80
1981	884	2120	0.42	290	748	0.39	753	1243	0.61
1982	754	2109	0.36	317	709	0.45	631	1257	0.50
5-year averages	579	1418	0.41	279	571	0.49	553	974	0.57
1983	538	2093	0.26	572	1147	0.50	831	1749	0.48
1984	575	1246	0.46	272	609	0.45	354	1212	0.29
1985	633	1903	0.44	353	665	0.53	579	1383	0.42

Table 16. Expected production schedule for Black Brook salmon incubation facilities.

Year	Brood[a] stock available	Expected[b] fry production ($x10^6$)	Expected[c] smolt production ($x10^5$)	Adult[d] production	Brood[e] returning
1985	1200				
1986	1200	1.65			
1987	1200	1.65			
1988	1200	1.65			
1989	1200	1.65	2.07		
1990	2000	1.65	2.07	20655	5422
1991	2000	2.75	2.07	20655	5422
1992	2000	2.75	2.07	20655	5422
1993	2000	2.75	2.07	20655	5422
1994	2000	2.75	3.44	20655	5422
1995	2000	2.75	4.44	34425	9037
1996	•				
1997	•				

[a]Brood characteristics: 3 females/male; 1.2 kg/female; 1800 eggs/kg.

[b]Egg-to-fry survival expected to average 85%.

[c]Based on an Age 3 smolt at average survial of 50% per year (i.e. 12.5% fry-to-smolt survival).

[d]Expected 10% average smolt to adult survival.

[e]Expect 65% commercial exploitation + 25% recreational catch.

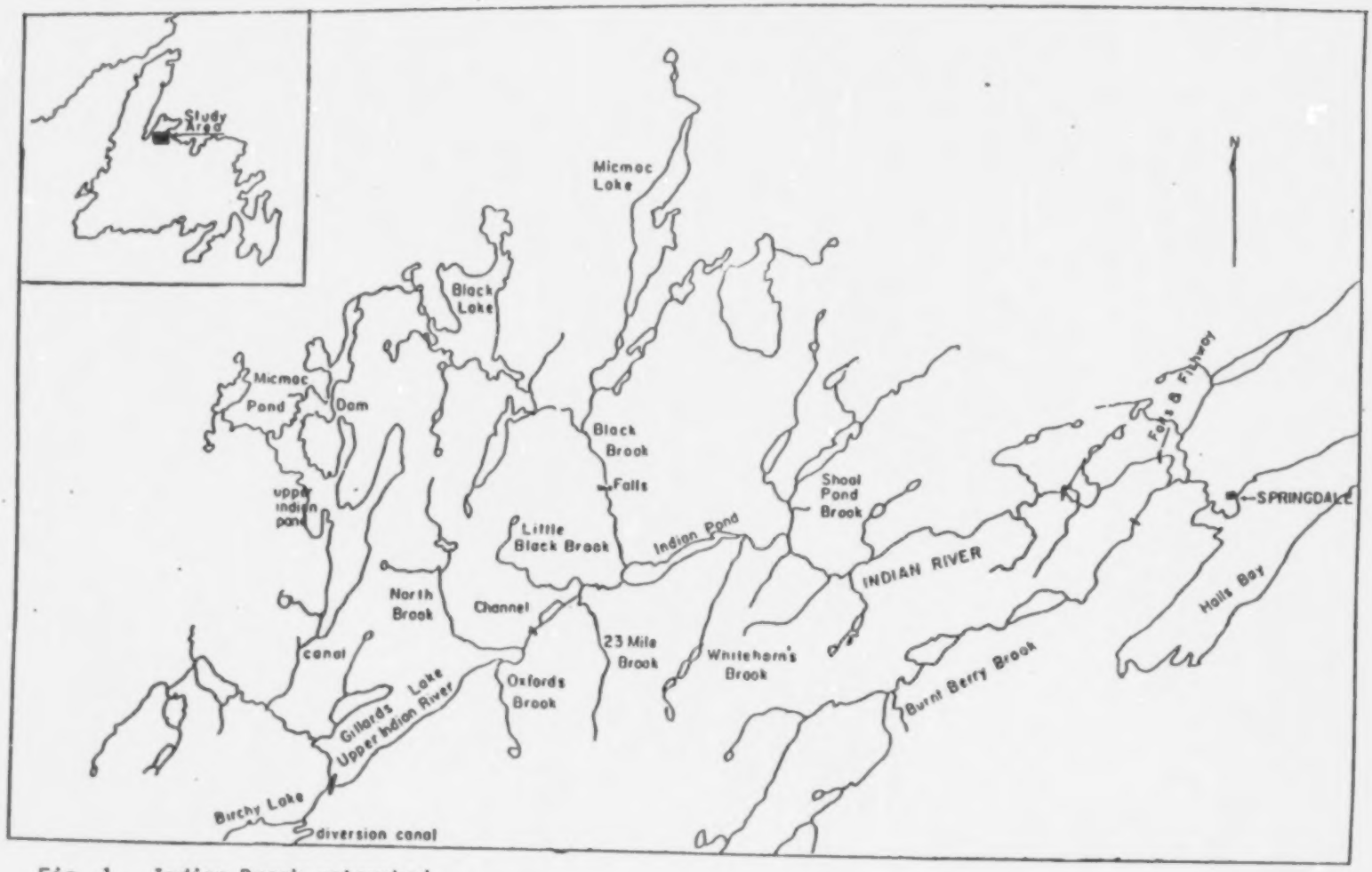


Fig. 1. Indian Brook watershed.

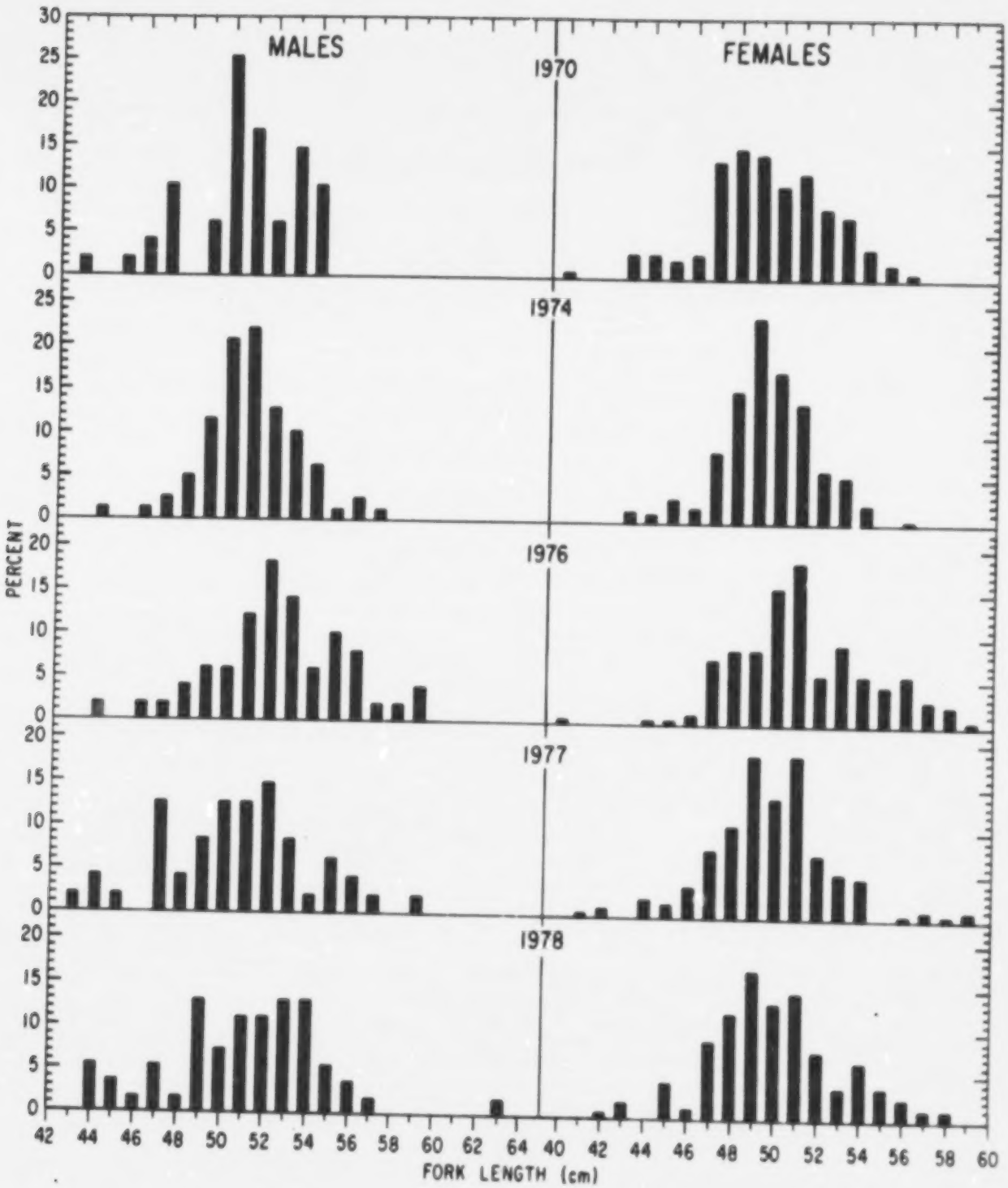


Fig. 2. Fork length and weight distribution of Indian Brook Atlantic salmon brood stocks.

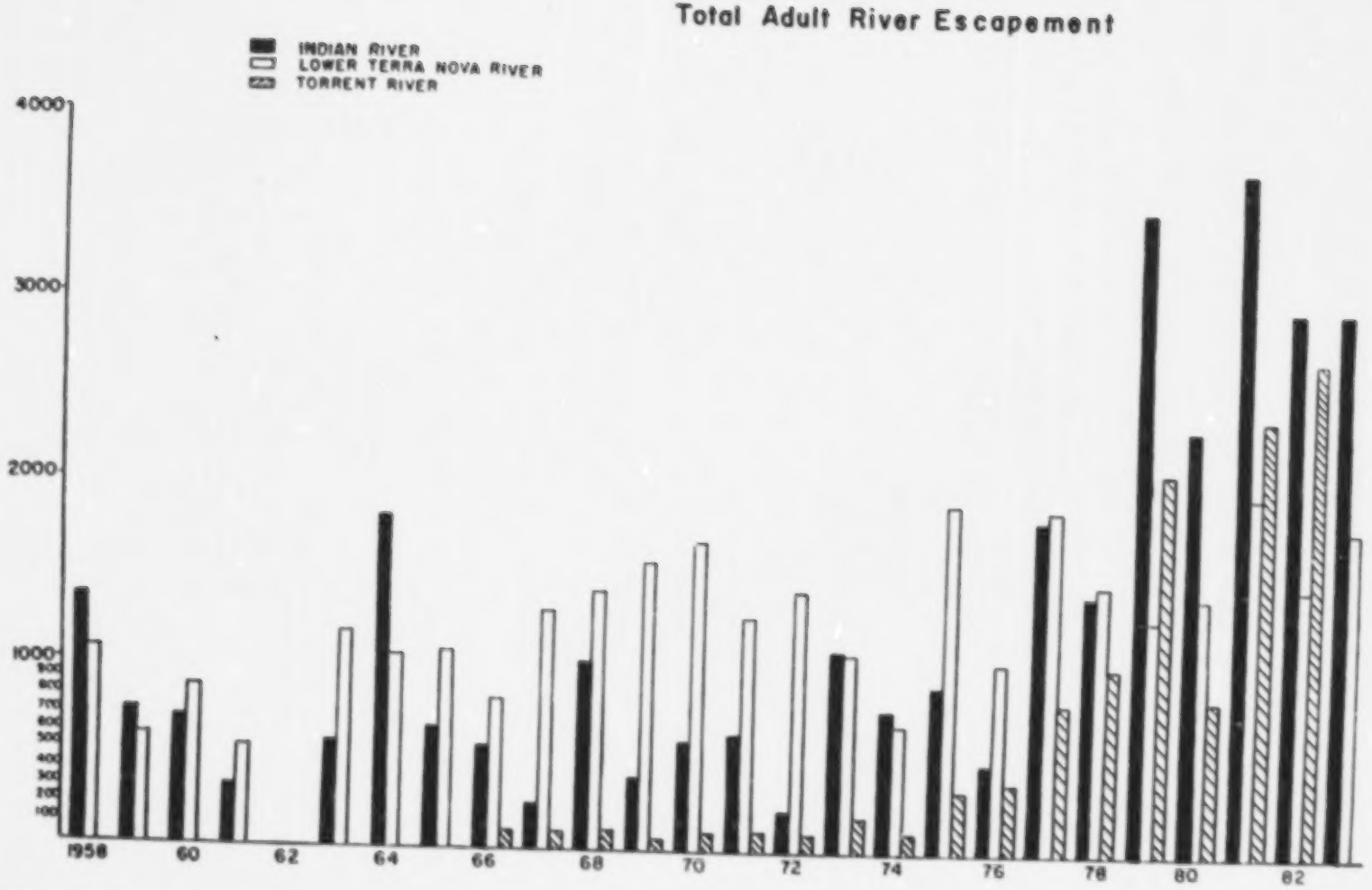


Fig. 3. Atlantic salmon escapement to Newfoundland rivers supporting enhancement activities.

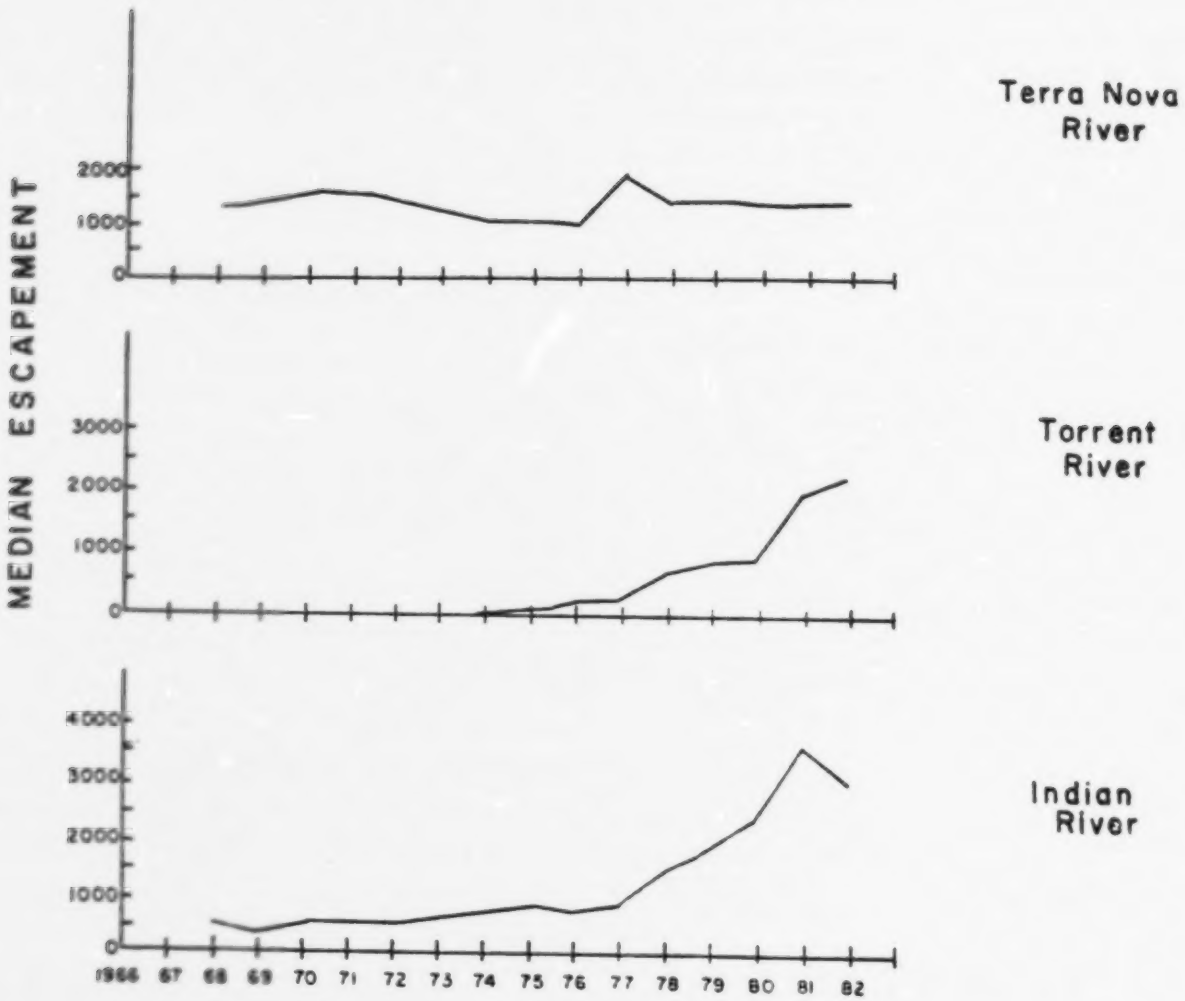


Fig. 4. Atlantic salmon production trends in Newfoundland rivers supporting enhancement activities.

Appendix 1 -- Experimental Design and Operating Plan for Black Brook, Atlantic Salmon Enhancement Facilities

The Black Brook Atlantic salmon enhancement project is a publicly sponsored initiative to demonstrate the merits of community involvement in a fishery related activity. A result of a five-year multidisciplinary, intergovernmental and interdepartmental planning effort, the Black Brook project reflects the diverse interests of its planners. Since project design has had to fit within the economic constraints of benefit:cost analysis, project operation must foster salmon production benefits to the traditional fishery harvest. Operation of the Black Brook salmon incubation facility provides an opportunity for research toward optimizing the lake-rearing aspect of salmon enhancement in Newfoundland while still supporting these harvests.

Sufficient background information has been gathered (Pepper et al. 1984, Pepper et al. 1985a) on which to plan the research component of the project. This information has shown that salmon fry distributed to lacustrine habitats have survival rates similar to fry stocked in riverine habitat. However, work to date has posed new questions, the most significant of which are:

1. Is consecutive annual stocking effective in realizing good juvenile survival in lakes, or would non-consecutive stocking be a more efficient means of contributing increased production to fishery harvests?

2. What stocking density is most effective in maximizing smolt production?

3. Is fry stocking an efficient means of smolt production from Newfoundland's standing waters or would a fall-fingerling be more appropriate?

4. What are the relative advantages of stocking lake vs stream habitat?

In terms of experimental design, these questions dictate a four-factor experiment that, in its simplest form, requires two levels per factor. This then implies a factorial experiment requiring 16 experimental treatments per replicate (Table 1.1). Unfortunately, an experiment of such magnitude cannot be accommodated at Black Brook due to physical limitations of the watershed.

Limitations

Examination of the Black Brook watershed reveals five lakes suited to the present experiments (Fig. 1.1): two that are relatively large, two that are quite small, and one that is intermediate in size. Juvenile salmon stocking opportunities in this area amount to 2000 ha of lake habitat within the Black Brook watershed and a similar amount of good lake and stream habitat scattered within the Indian Brook watershed (Fig. 1), of which Black Brook is a tributary. Of major concern in designing stocking experiments is the means

whereby these experiments will be assessed. Since fry-to-smolt survival is one of the main criteria by which salmon stocking projects are judged, smolt enumeration facilities will be required at each stocking site.

Definition of a stocking experiment for these salmon rearing opportunities requires consideration of the number of fry that can be made available in support of stocking requirements. The present Black Brook salmon incubation facility has an egg capacity of about two million and is expected to provide an annual supply of 1.7 million fry through its first six years of operation. Although the present facility has considerable expansion potential, present constraints include demonstration of increased salmon production benefits and increased brood availability prior to considering an expansion phase.

Black Brook Salmon Enhancement Project

The Black Brook project is intended to demonstrate the social, scientific, economic, and conservation benefits and potentials of salmon enhancement in Newfoundland. Black Brook enhancement goals are summarized in Table 1.2. Although funded within the context of community involvement in salmon enhancement, the Black Brook project provides the opportunity to assess potential and refine technology for similar community-based projects in other areas of Newfoundland. With approximately half of the project's cost coming from government departments outside of DFO, the Black Brook salmon enhancement project is directed by an interagency steering committee chaired by DFO (Fig. 1.2). These considerations have influenced, to varying degrees, the experimental design (as it relates to the general operating plan) for the project.

In addition to its obligations relative to demonstrating bio-technical advancements in enhancement methodologies, the Black Brook project represents a social milestone in project motivation. The Department of Fisheries and Oceans (DFO) is providing the technical framework in which the project operates. The project is managed jointly by two Regional Economic Development Associations as a community initiative towards regional development and resource base stabilization. In consideration of the fact that "One quarter of the population in the four Atlantic provinces lives in small fishing communities, more than half of which have single-sector economies that are dependent almost entirely on fishing and fish processing.", and the recommendation that ". . . all concerned (resource users) appreciate that they are working for themselves and their community . . .", the Black Brook project is a move toward overcoming the "we/they" attitude that has contributed to resource shortages in Atlantic salmon stocks. Community involvement and public participation in the day to day operation of salmon enhancement projects is an example of a means to "Create mechanisms for more effective interpretation of scientific material to the concerned public and greater contact between resource biologists and fishermen's groups.". The Black Brook salmon enhancement project must demonstrate that the traditional salmon fishery and the region as a whole can benefit from cooperative liaison between Government and the public to stabilize salmon production.

The Black Brook project, and the community and public involvement initiative it represents, is a concerted effort to break away from the

historical trend of ". . . individuals and organizations . . . putting the blame for the industry's (fishing) problems on everyone else while accepting none of it themselves.". Since there is at present simply not enough natural salmon production to support an economically viable salmon industry for all the people who would like to participate, it has been common management practice to reduce fishing effort by limiting the number of participants in the salmon fishery. However, it also is recognized that ". . . a reduction in the number of fishermen will not in itself ensure that reasonable incomes will be earned by the remaining participants" (all quotes from Kirby 1982). Hence, a major initiative currently underway within the Newfoundland Region of Fisheries and Oceans is to work directly with user groups, both to educate users to the fact that the salmon resource is finite and, to encourage public responsibility with respect to long term management of the resource.

As users and managers of the resource, especially with respect to application of enhancement methodologies, public groups are being exposed to technology transfer programs that provide the essential concerns and precautions pertinent to working with and manipulating salmon stocks. As well, these groups are given instruction with regard to existing fishery legislation, fishery policy and resource management philosophies on fishery resources. One of these policies, an adjunct to the fishery management objective to ". . . generate the maximum continuing economic and social benefits . . ." (Anon. 1980), is that resource managers do not wish to substitute artificial production for natural salmon production but rather, wish to augment natural production where this can be done without peril to the natural stock.

Community Involvement

In the context of the present (1986) situation in Atlantic Canada, where it has been recognized that fishery resources no longer are sufficient to support present exploitation rates (Kirby 1982), the challenge to resource management is ". . . to minimize disruptions in the social fabric of Atlantic Canada . . ." while attempting to motivate a shift in traditional fishing attitudes away from simply chasing fish to partaking in cooperative ventures to stabilize production of fish. This ". . . evolution, not revolution . . ." aspiration must be pursued in a well-structured and tangible process wherein both the goals and the methods are advocated by the public at large. This process of self-motivation requires that government be perceived as lending a helping hand to help people help themselves. Such is the goal of community involvement in salmon enhancement. This active participation in support of salmon production, hence fishery stability and regional economic and social stability is the example;

> ". . . what conservation is all about, to provide man with the amenities of life including those creatures which contribute to the aesthetic aspect of human existence. Anything else is not conservation but mere conversation." (White-Stevens 1976).

Assuming that public groups will seize upon the opportunity to participate in resource management and thereby foster long-term benefits to their communities, the challenge to government (the historic bearer of such

responsibility) is to direct community energies to assure that transfer technologies are applied constructively to the mutual benefit of both social and biological systems. Both of these systems have multifaceted and interdependent "conscious elements" that may yield additional cultural and monetary benefits under responsible management. Salmon enhancement projects, when operated under public motivation, must assume the same biological constraints that apply to government directed projects.

Coordination

One of the first concerns that must be addressed in implementing programs of community involvement in salmon resource development is that of providing training and technology transfer to the interested public. Design and operation of successful salmon development projects requires considerable planning. Of course, it will be up to the interested public to advocate what it would like to do towards stabilizing and enhancing salmon production. The onus then is on the resource manager to determine that the proposed initiative is feasible and to assure that the activities proposed are compatible with the characteristics of the watershed and with the salmon stock to which the development strategy is to be applied.

Experimental Design

Recognizing experimental limitations (i.e. the number of potential stocking sites, availability of brood stock, and the present egg capacity of the Black Brook facility), the Black Brook salmon enhancement experiment is designed to determine the relative survival and growth rates of unfed fry vs fall-fingerlings and the consequences of consecutive vs non-consecutive stocking. This limitation in the scope of the experiment, to two rather than four factors, limits experimental design to four cells per replicate (Table 1.3). Additional factors that might be added to the Black Brook experimental design (for example, stocking density and stream stocking) await implementation of an expanded salmon enhancement program that will support concurrent projects in other areas of Newfoundland.

Five lakes are being used in the present experiment to accommodate the two-factor experiment design. Stocking is at a fixed density of 1000 per hectare (Pepper et al. 1984) and requires annual production varying from 60 thousand to about 1.4 million fry [this stocking density is thought to be conservative; a literature review (Pepper et al. 1984) of stocking densities revealed a range of from 600 to greater than 200,000 fry per ha].

Fall-fingerlings are being produced at the DFO rearing channel on Indian Brook with fry from the Black Brook incubators. In its present configuration, the Indian Brook channel has a fall-fingerling production capacity of 200,000. In order to maintain a fixed stocking density of 1000 per ha to the experimental lake-stocking project, the size of the largest single lake that can be stocked with fall-fingerlings therefore is 200 ha. In recognition of these constraints, experimental design for the Black Brook project is a fixed-effects model involving four replicates per treatment. This implies a possible 25-year life span for the project (Table 1.4).

Stocking Plan and Analyses

The experiment involves stocking fry in the two largest lakes (Micmac Lake and Gull Pond), fall-fingerlings in the two smallest lakes (Upper Micmac and Traverse ponds), and alternately stocking fry and fall-fingerlings in the intermediate-sized lake (Wolverine Pond). Factors are pursued in a cross-over design because of the possibility of confusing experimental treatments with year-to-year environmental variability over an extended time period.

The experiment began in 1982 with release of fall-fingerlings to Upper Micmac and Traverse ponds (Fig. 1.1). Consecutive-year releases of fall-fingerlings are scheduled for Upper Micmac from 1982 to 1984, Traverse Pond from 1986 to 1988, again in Upper Micmac from 1992 to 1994, and in Traverse Pond from 1996 to 1998. Alternating with this sequence is non-consecutive-year stocking of fall-fingerlings in Traverse Pond in 1982, in Upper Micmac in 1988, in Traverse Pond (again) in 1992, and finally in Upper Micmac in 1998.

Stocking of unfed fry commenced in 1985. Consecutive-year fry stocking will be pursued in Gull Pond until 1988, in Micmac Lake from 1989 to 1991, again in Gull Pond from 1996 to 1998, and finally in Micmac Lake from 1991 to 2001. Alternating with this sequence is non-consecutive fry stocking in Micmac Lake in 1985, Gull Pond in 1992, Micmac Lake again in 1995, and finally in Gull Pond in 2002.

Both factors (fry vs fall-fingerlings) are being evaluated for the intermediate size lake since the life-stage factor is being pursued in the large and small lakes in a biased design, with the smallest fish going to the larger lakes and the larger fish going to the smaller lakes. This intermediate pond "cross-over" is undertaken in consideration of Ricker (1932) who indicated that larger lakes tend to produce larger fish.

In anticipation of three-year-old smolts from both of the experimental factors (fed vs non-fed fry and consecutive vs non-consecutive stocking), three-year blocks between stocking sequences provide opportunity for young fish to grow and emigrate from the ponds as smolt, with a follow-up time for at least partial recovery of the ponds' energy reserves in the lower levels of the food web. This fallow period attempts to avoid confounding experimental effects.

There are two variables of particular interest in evaluating these experiments: 1) average instantaneous mortality from stocking of juveniles to smolts out, and 2) average instantaneous growth. The number of unfed fry stocked will be estimated as a statistical parameter with a 95% confidence interval. However, since fall-fingerlings will be marked prior to release, this variable in the instantaneous mortality equation will be represented by an accurate count, as will the number of smolt emigrating from each of the study locations. Instantaneous growth will be calculated from the average weight of juvenile salmon stocked and the average weight at smoltification. Both instantaneous growth and instantaneous mortality will be used to calculate the rate of change in biomass (Ricker 1975) of juvenile salmon throughout their freshwater residence period. Mean instantaneous rate of change in biomass is

the response variable that is being evaluated in analyses of these stocking experiments.

Predation

Potential predation on newly-released juvenile salmon by brook trout and American eel is a significant concern in these lacustrine stocking experiments. Also, post-yearling salmon parr may represent a significant predatory pressure (Symons 1974) during consecutive-stocking periods in which swim-up fry are being released. Potential predator monitoring will be undertaken on alternate days over a two-week period (seven samples) following fry distribution. Gill nets and baited lines (for capturing eels) will be set at fry distribution sites within six hours of fry distribution and will be examined four times over each 24-hour period. As many as 12 eels and up to 12 trout of > 15 cm fork length will be sacrificed each day for stomach analyses. A random sample (10%) of salmon parr of > 10 cm fork length also will be sacrificed each day. Much the same procedure will be followed with respect to fall-fingerling distribution except that post-yearling salmon parr will not be sampled.

Early Maturation

Another concern of stocking lakes with juvenile salmon is a possible increase in the incidence of early maturation among male parr. The incidence of precocious males will be evaluated during electrofishing surveys in Gull Brook (between Gull Pond and Traverse Pond) from mid-September to late October. All precocious male parr Age 5 and up (> 20 cm fork length) will be removed from the population in an attempt to deter residualism (failure to smoltify by Age 3) in the salmon stock. All other precocious parr will be weighed, measured, scale sampled, and released back into Gull Brook. In late September, one lake trap net will be set for one night in each lake to allow evaluation of growth characteristics of non-maturing parr. Samples of parr from the lake trap nets also will be weighed, measured, scale sampled, and released at the site of capture to facilitate comparison of possible bimodality in growth rate between early-maturing (precocious parr) and non-maturing components of the parr population.

Smolt Enumeration

Smolt enumeration weirs will be monitored for each study site of the experiment: on Gull Brook, at Traverse Pond, at Upper Micmac, at Micmac Lake, and at Wolverine Pond. At each site, smolt will be enumerated and a subsample of smolt will be measured and scale sampled to facilitate growth comparisons among the five ponds. From previous studies of salmon nursery areas within the Black Brook watershed (Pepper et al. 1985a), the average smolt size was approximately 16 cm (Fig. 1.3) and the coefficient of variation across the subsamples was 10%. Hoping to be able to detect, with a 90% certainty, a 1.0 cm difference (6.25%) in smolt mean fork length between any two of the five lake populations, at the 5% level of significance, smolt sampling will be at least 55 specimens per sample site (Sokal and Rohlf 1969). This sampling rate will be maintained over all smolt emigrations to support histological, physiological and anatomical appraisal of smolt quality and rearing history. If a significant difference in smolt size is detected among the five lakes, its

biological significance in terms of its effect on adult salmon size and survival potential will be evaluated.

Expectations

Initial experiments with lacustrine rearing of juvenile salmon revealed fry-to-smolt survival ranging from a high of 20% to a low of less than 1% (Pepper et al. 1985a). Survival estimates for North American stream habitats, as reported in the literature, have ranged from 2% to 12% (Elson 1962; Chadwick et al. 1978). Egglishaw and Shackley (1980) have reported somewhat higher survival from their stocking experiments in Scotland. With this range of values, it is difficult to make concise comparisons of the relative production merits of lacustrine and stream habitats. Considering that the ultimate goal of salmon enhancement projects is cost-effective salmon production, present experiments must conform with some minimum juvenile salmon survival in order to demonstrate potential long-term viability of the pond-ranching strategy. The present economic analysis of the Black Brook project is based on fry-to-smolt survival of 12.5%. With a benefit:cost ratio of 1.72, simple linear interpolations indicate freshwater survival could drop to as low as 8% before economic values would erode to the break-even point. Thus, assuming a three-year smolt, the present Black Brook experiment is required to demonstrate annual average freshwater residence survival of greater than 43%.

The Black Brook project is based on an evolutionary operations plan (Hicks 1966, as per Table 1.5) and requires interim analysis of the stocking experiment after completion of each of the four cycles of the 25-year program. First project results from Black Brook occurred in 1984 with smolt runs from Traverse and Upper Micmac Ponds. Since this experiment requires a time series of data, statistically important results will not be available until the last smolt emigrations in 2006. Valuable interpretative data will be available on completion of each of the four cycles.

Should the lacustrine stocking experiments encounter major biological setbacks (such as heavy predation by resident species or extreme incidence of early maturation leading to unacceptable mortality levels), evidence of these problems will be available within two years of undertaking consecutive fry stocking. Such data will provide the means by which to define an alternate operating plan or, in the worst case, to redirect the primary mandate of the project. Increased salmon production resulting from these experiments is expected in 1990 as a result of smolt emigrations in 1989. Accordingly, in anticipation of increased brood availability at that time, Black Brook facilities may be expanded in 1990 to twice the egg capacity of the present facility.

Harvest Benefits

Lacustrine habitats will be left fallow (i.e. no fry stockings) between replicates of experimental treatments to allow for at least partial recovery of energy reserves in the lower levels of the food web. Although these experimental strategies ultimately will help refine stocking procedures, such fallow periods may degrade short-term production benefits. However, all habitats of the Indian Brook watershed outside of the Black Brook tributary can

be brought into production on an annual basis to sustain minimum required economic benefits.

It is through careful project design and operation that the Black Brook project will meet its social, scientific, economic and conservation obligations and will contribute to future salmon resource development initiatives in Newfoundland and Labrador.

TABLE 1.1

2^4 FACTORIAL EXPERIMENT FOR SALMON ENHANCEMENT

		LIFE STAGE 1		LIFE STAGE 2	
		DENSITY 1	DENSITY 2	DENSITY 1	DENSITY 2
STOCKING SEQUENCE 1	HABITAT 1	VARIABLE 1 Z / VARIABLE 2 G			
	HABITAT 2				
STOCKING SEQUENCE 2	HABITAT 1				
	HABITAT 2				

G = INSTANTANEOUS GROWTH

Z = INSTANTANEOUS MORTALITY

Table 1.2. Goals of Black Brook, Atlantic salmon enhancement.

Goals of Project

1. Pilot community involvement in Atlantic salmon enhancement by:

   - transferring appropriate level technologies to public groups to support publicly operated salmon enhancement projects;
   - increasing public awareness of the principles and limitations of renewable resource management; and,
   - demonstrating social benefits of community participation in salmon resource management.

2. Increase salmon production in the Indian Brook watershed by:

   - distributing salmon fry from artificial incubators to selected habitats of Indian Brook and tributaries;
   - accelerating growth of juvenile salmon to decrease average smoltification age of salmon stock and thereby increase the freshwater survival of juveniles; and,
   - depressing the incidence of early maturation among male parr thereby encouraging increased smolt production.

3. Act as a focus of technology transfer to public/private interests for potential application in salmonid aquaculture by:

   - demonstrating biotechnology applications for production of salmonids;
   - demonstrating natural and semi-natural rearing techniques for juvenile Atlantic salmon; and,
   - evaluating kelt salmon reconditioning/fattening techniques as to their potential to contribute to development of infrastructure support to cottage industry aquaculture.

Goals of Experiment

1. Refine juvenile salmon stocking procedures for lake habitat by:

   - investigating, through structured experimentation, the relative merits (i.e. biological and economic efficiencies) of stocking fed as opposed to unfed fry and of consecutive as opposed to non-consecutive stocking;
   - comparing results of lacustrine stocking with those from stream stocking in other parts of Indian Brook (i.e. smolt weirs) to establish the relative merits of early rearing habitat types;
   - evaluating the rate of adult salmon returns from the juvenile salmon stocking experiments (i.e. counts at Indian Brook headwater dam and at Black Brook fence); and
   - examining adult salmon stock characteristics as a function of juvenile growth rates.

Table 1.2 (cont'd)

2. Refine artificial feeding techniques for Atlantic salmon in semi-natural culture by: - rearing salmon fry in a stream rearing channel to the fall-fingerling stage so as to maximize growth and survival; - rearing salmon fry in floating lake cages to the fall-fingerling stage and comparing growth and survival rates with those for the rearing channel; - identifying a range of salmon diet items that will impart early rearing growth and survival advantages to salmon fry; and, - determining relative efficiencies of early rearing techniques for salmon fry by comparison of growth characteristics of wild vs semi-naturally reared fry.

TABLE 1.3

2^2 FACTORIAL EXPERIMENT FOR SALMON ENHANCEMENT

	LIFE STAGE 1	LIFE STAGE 2
STOCKING SEQUENCE 1		
STOCKING SEQUENCE 2		

Table 1.4
Black Brook Incubation and Indian Brook Fall Fingerling Facilities
Primary Experiments, 1982-2002
(fry required in millions)

Pond stocked	Product stocked	Year																			
		82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	2000	01	02
Upper Micmac	FF[a]	0.06	0.06	0.06				0.06				0.06	0.06	0.06				0.06				
Traverse	FF[a]	0.14				0.14	0.14	0.14				0.14				0.14	0.14	0.14				
Wolverine	Fry			0.15	0.15	0.15									0.15							
	FF[a]									0.15	0.15	0.15							0.15			
Gull	Fry					1.00	1.00	1.00				1.00				1.00	1.00	1.00				1.00
Micmac	Fry				0.79				0.79	0.79	0.79				0.79				0.79	0.79	0.79	
Total fry required		0.20	0.06	0.21	0.94	1.29	1.14	1.20	0.79	0.94	0.94	1.35	0.06	0.06	0.94	1.14	1.14	1.20	0.94	0.79	0.79	1.00

[a] Assuming 50% captivity survival to fall fingerling release.

Table 1.5. Evolutionary Operation Work Sheet (from Hicks 1966).

Y_1 = non-consecutive stocking fry
Y_2 = consecutive stocking fall fingerlings
Y_3 = non-consecutive stocking fall fingerlings
Y_4 = consecutive stocking fry

Cycle: n = _____

Response*: G-Z

Project: Black Brook
Phase: _____

Date: Day _____ Month _____ Year _____

Operating Conditions	Y_1	Y_2	Y_3	Y_4	Calculation of standard deviation
i Previous cycle sum	___	___	___	___	Previous sum S =
ii Previous cycle average	___	___	___	___	Previous averages =
iii New observations	___	___	___	___	New S = Range x fk, n =
iv Differences [(ii) less (iii)]	___	___	___	___	Range =
v New sums	___	___	___	___	New Sum S =
vi New averages	___	___	___	___	New Averages = $\frac{\text{New Sum S}}{n-1}$ =

Calculation of Effects	Calculations of Error Limits
Life history effect = $\frac{1}{2}(\bar{Y}_2 + \bar{Y}_3 - \bar{Y}_1 - \bar{Y}_4)$ =	For New Average $\frac{2}{\sqrt{n}}$ S =
Stocking sequence effect = $\frac{1}{2}(\bar{Y}_2 + \bar{Y}_4 - \bar{Y}_1 - \bar{Y}_3)$ =	For New Effects $\frac{2}{\sqrt{n}}$ S =
LHE x SSE = $\frac{1}{2}(\bar{Y}_1 + \bar{Y}_2 - \bar{Y}_3 - \bar{Y}_4)$ =	For change in Mean $\frac{1.78}{\sqrt{n}}$ S =

* G = $\log_e$(Wt-Wo)/(smolt age)
  Z = -($\log_e$ Nt+1 - loge Nt)/(smolt age)

Response = instantaneous rate of change in bulk

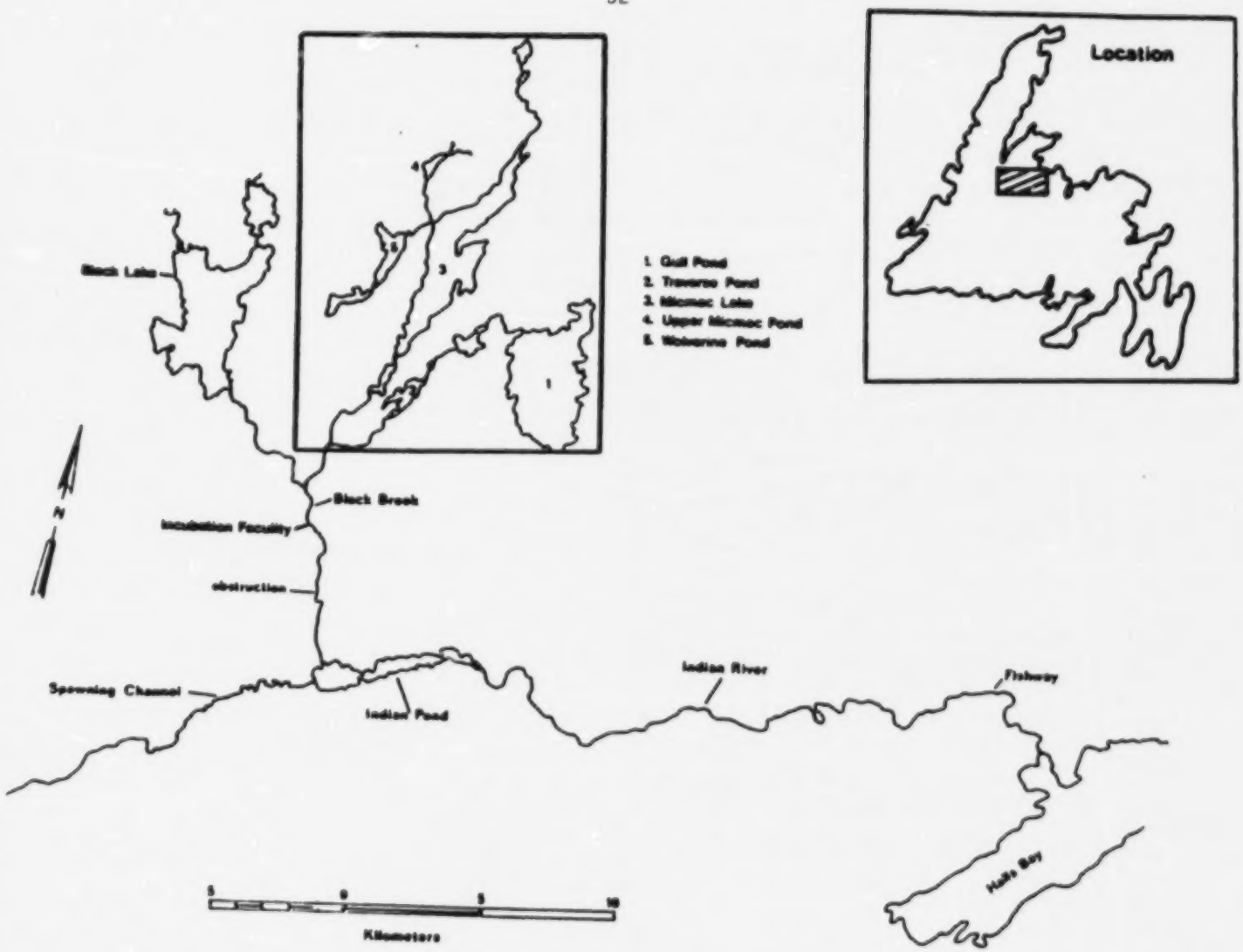
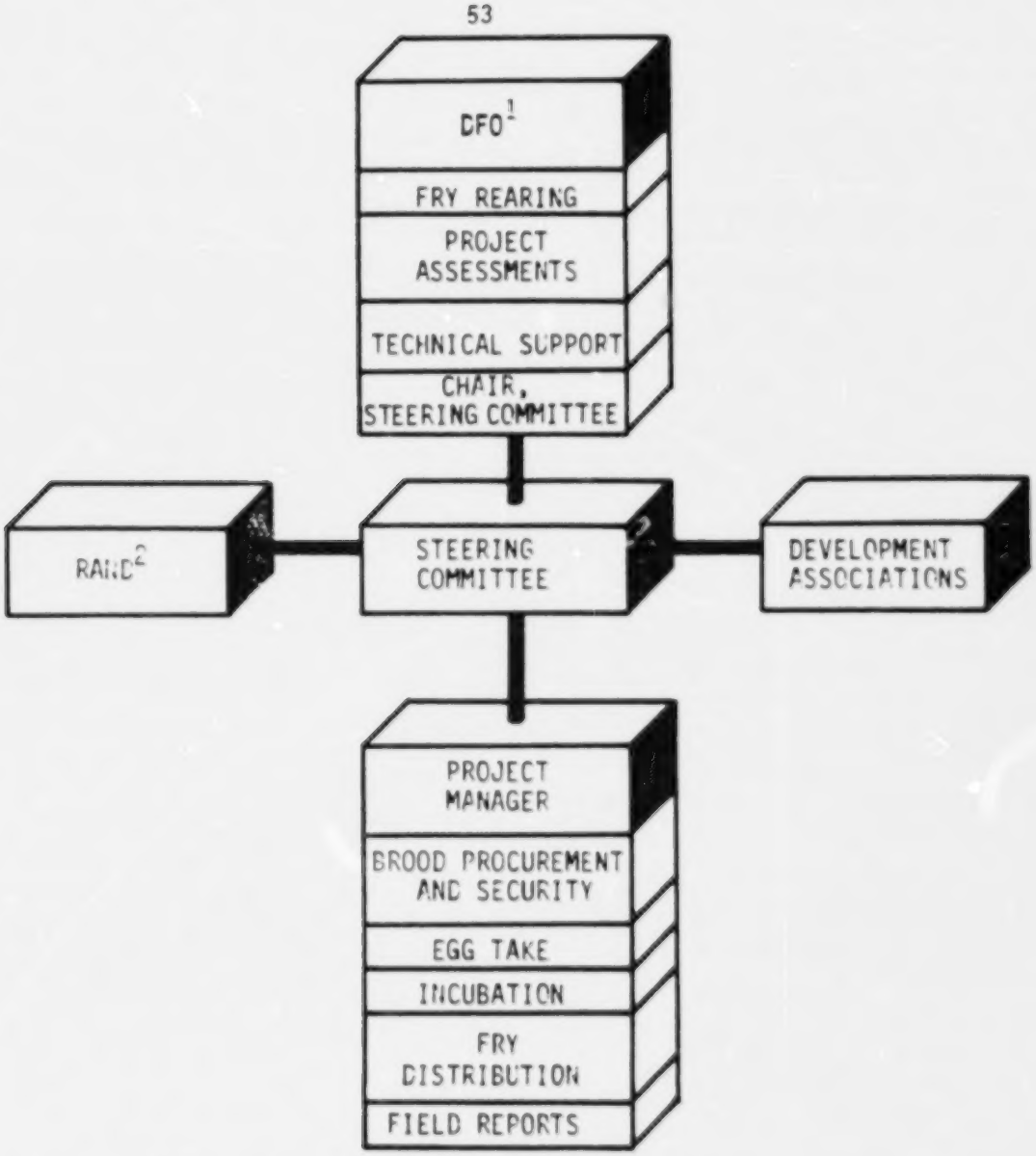


Fig. 1.1. Juvenile Atlantic salmon stocking areas for Black Brook enhancement experiments.



[1]Department of Fisheries and Oceans, Covernment of Canada.

[2]Department of Rural, Agricultural and Northern Development, Government of Newfoundland and Labrador.

Fig. 1.2. Steering committee participation for Black Brook, Atlantic salmon enhancement project.

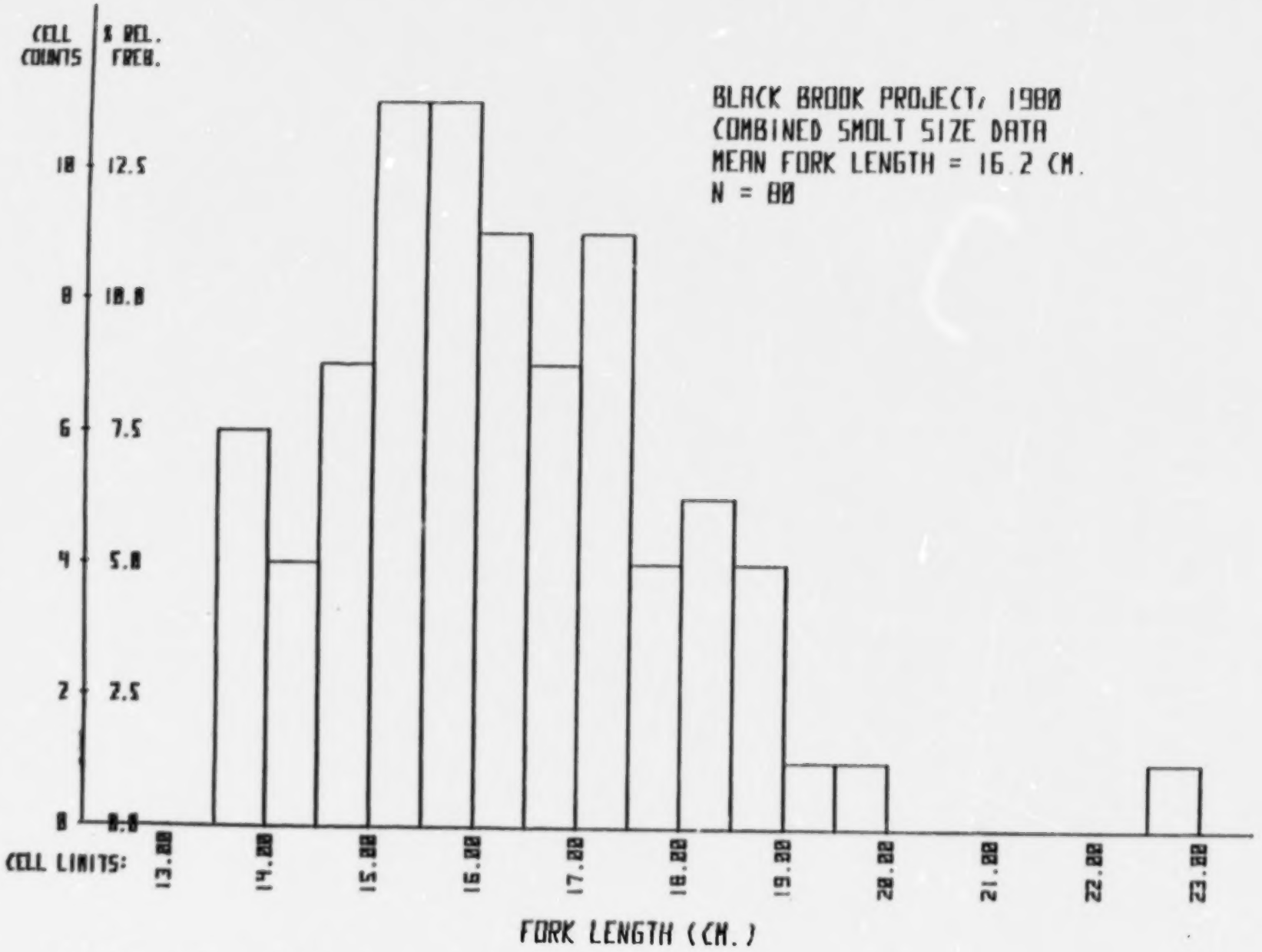


Fig. 1.3. Atlantic salmon smolt size distribution for Black Brook lacustrine habitats.

Appendix 2 -- Procedures for Data Analyses for Black Brook, Atlantic Salmon Enhancement Project

The public participation component of the Black Brook project has the limitation that people involved in day-to-day activities are not likely to be highly trained in salmon enhancement technologies. Most of these people are unlikely to have been exposed to ecological concepts or principles of experimental design. It is likely that enhancement projects will experience significant employee turnover from year-to-year and that this turnover will deter development of a skilled labor pool that otherwise would support continuity of project operations. Therefore it is important for DFO to provide ongoing technical liaison for technology transfer, for overviewing annual operating plans, and for appraising project results. The purpose of this appendix is to provide a layman's perspective on the goals, limitations and appraisal mechanisms of the Black Brook project.

A significant challenge to salmon enhancement planners is that of maintaining continuity of project operation over the extensive time frames required to obtain results from their experiments. Salmon enhancement projects suffer considerable delays between implementation of projects and the occurrence of results to the project due to the five-year life cycle of most of our Newfoundland Atlantic salmon stocks. This limitation to project operation causes enhancement planners considerable difficulty in that the greater the interval between costs incurred by a project and the benefits accruing to the project (enhanced salmon production):

1. the lower the benefit/cost ratio for the project;
2. the greater the time required to build up a sufficient supply of brood stock to support the enhancement project; and,
3. the greater the likelihood of staff turnover during the interval between project implementation and project completion.

Of these three limitations, the first two usually are overcome by careful project planning so that only those projects that are economically sound, in spite of life cycle time delays over which we have no control, are allowed to proceed. The third problem is dealt with by assuming that staff turnover will take place and that new staff will require considerable guidance to assure that they understand the goals of the project and the operational logistics required to support these goals. This appendix to the Black Brook operations plan is intended to encourage continuity of project operation over its projected 25-yr life expectancy. If the project is blatantly wrong in orientation (i.e. extremely low numbers of smolt migrating from the study ponds), this should be evident within the first few years of project operation. In such a situation, the analyses as described in this appendix may not be required. If freshwater survival through the first few years of stocking is much less than 8% on average, either the source of this mortality will have to be identified and remedied, or the project will have to be reoriented. Within the present experimental design is the limitation that, while we will have the means to determine if the project is falling short of its expectations (poor freshwater

survival), we will not be able to make any objective claims about project success until at least 1995. Thus, considering the necessity of much patience in collecting sufficient data in support of decision criteria, and of catering to production requirements on which the project has been justified, continuity of operational logistics is essential.

The Black Brook, Atlantic salmon enhancement project is not only a means of securing additional production to the Green Bay area salmon fishery; it is intended as a pilot project to refine stocking strategies for standing waters. There are many research aspects to the project that must be highlighted and assured, relative to data recording and analysis of results, in order to illuminate the principles that will support additional standing water enhancement projects in other parts of Newfoundland and Labrador.

Research Requirements

The Evolutionary Operations (EVOP) plan, on which the Black Brook experiment is based, was developed as a tool for increasing industrial productivity. EVOP is used by industry to identify production processes that improve quality and/or increase output in an industrial setting. Relative to application at Black Brook, EVOP requires that production data be reviewed periodically to determine if the experiment has produced a significant result and then, based on initial data, provide an objective decision mechanism on which to redefine experimental variables (i.e. stocking strategies) to maximize production. By applying the EVOP procedure to the Black Brook project, we hope to identify juvenile salmon stocking methods that maximize smolt production per unit of enhancement effort (ultimately, maximum benefit per unit of enhancement cost). Though Black Brook experiments have a potential 25-yr life span, evaluation of smolt production data by a review board (i.e. project steering committee), according to criteria presented in this appendix, could identify an efficient juvenile salmon stocking plan as early as 1995. If this were the case, then it would be sound, both mathematically and biologically, to redirect the project to investigate other enhancement strategies or simply to dedicate project facilities to maximizing annual smolt production per unit of salmon rearing habitat.

Provision of data to identify an effective stocking strategy for Black Brook salmon enhancement requires consideration of the equations used to provide analysis criteria. These equations are defined at the bottom of Table 1.5 and are as follows:

Instantaneous growth (G)
= ($\log_e$ mean smolt weight - $\log_e$ mean fry weight)/mean smolt age

Instantaneous mortality (Z)
= -($\log_e$ number smolt produced - $\log_e$ number juveniles stocked)/mean smolt age

These two equations require the following activities and calculated variables:

1. Every second day that fry are enumerated at the Black Brook facility, a subsample of at least 20 specimens, from each incubator chamber, must be weighed (nearest 0.01 g) and measured (nearest 0.1 mm). These specimens must be processed within hours of being sampled. Data must be recorded in the project log book with appropriate notations as to which rearing option (experimental effect) the day's fry accumulation is applied;

2. An estimate must be made (Pepper 1984) of the number of juvenile salmon applied to each of the experimental factors (see Table 1.4 for guidelines on appropriate numbers for stocking);

3. For each year of smolt emigration, smolt must be counted (daily throughout the emigration period) and a subsample weighed (nearest g), measured (nearest mm) and a scale sample taken. A minimum of 55 specimens must be sampled each year from each of the smolt enumeration weirs (at outlets of Upper Micmac, Wolverine Pond, Micmac Lake, Gull Pond and Traverse Pond) giving a sample of 55 specimens x 5 locations = 275 smolt data records per smolt run. Scale samples must be examined under a microscope to determine the age at smoltification. Anticipating that smolt runs will be composed of a mixture of Age 2, 3 and 4 smolt, age frequencies from the subsamples will be used to calculate the approximate number of smolt of each age category migrating each year from the study sites. As an example:

- if a year-class (i.e. 1985) produced 150,034 smolt, 3.33% of which were Age 2, 93.33% were Age 3 and 3.33% were Age 4, then the run would have been composed of approximately 5000 2-yr smolt, 140034 3-yr smolt and 5000 4-yr smolt.

These data are required in order to calculate average smolt age for use in the instantaneous growth and mortality equations described above. This calculation is performed as:

- mean smolt age = ((# of 2-yr smolt x 2) + (# of 3-yr smolt x 3) + (# of 4-yr smolt x 4)) / (# of 2-yr smolt + # of 3-yr smolt + # of 4-yr smolt)

Example of Calculations

Assume that non-consecutive fry stocking has resulted in these data:

1. Number of fry stocked = 789653

2. Number of smolt produced from non-consecutive fry stocking:
   2+ = 5000
   3+ = 140034
   4+ = 5000

3. Mean weight of fry stocked = 0.142 g

4. Mean weight of smolt produced = 43.3 g

When we examine these data, we must consider what we are hoping for in terms of the outcome of the experiments. First, we hope to get a large number of smolt relative to the number of underyearling salmon that were released to the ponds (i.e. low mortality from time of stocking to time of smolt escapement). We would like also to see weight increase rapidly from the time of release to the ponds to the time of smolt escapement (i.e. high growth rate). By calculating Z and G (as above) we are able to quantify mortality and growth throughout the freshwater residence period. However, these two factors both require evaluation of average smolt age. From the calculation of mean smolt age described above we have:

$$\begin{aligned}\text{mean smolt age} &= ((5000 \times 2) + (140034 \times 3) + (5000 \times 4)) / \\ &\quad (5000 + 140034 + 5000) \\ &= (10000 + 420102 + 2000) / 150034 \\ &= 450102 / 150034 \\ &= 3.00\end{aligned}$$

We now can use the equations for Z and G:

$$\begin{aligned}Z &= -(\log_e 15\,034 - \log_e 789653) / 3.00 \\ &= -(11.9186 - 13.5793) / 3.00 \\ &= -(-1.66073) / 3.00 \\ &= 1.66073 / 3.00 \\ &= 0.553577\end{aligned}$$

$$\begin{aligned}G &= (\log_e 43.3 - \log_e 0.142) / 3.00 \\ &= 3.76815 - (-1.95193) / 3.00 \\ &= 5.72008 / 3.00 \\ &= 1.90669\end{aligned}$$

Although we now have quantified the variables of mortality and growth, we are only part way to fulfilling the desire to have only one variable on which to base our analysis of the experiment. By subtracting our mortality factor from our growth factor, we calculate our response variable for the Black Brook experiment, namely mean instantaneous rate of change in biomass (Ricker 1975). For the above example:

$$\begin{aligned}R &= G - Z \\ &= 1.90669 - 0.553577 \\ &= 1.35311\end{aligned}$$

It should be recognized at this point that this value is only one of four such values that will be required per stocking cycle. Similar calculations will be required for each of the three remaining experimental situations (i.e.

consecutive fall-fingerling stocking, non-consecutive fall-fingerling stocking and, consecutive fry stocking). The primary analysis then will consist of evaluation of consecutive and non-consecutive fry stocking in Gull Pond and in Micmac Lake and, consecutive and non-consecutive fall-fingerling stocking in Upper Micmac and Traverse Ponds.

Calculations for these primary analyses are tedious. They are, however, relatively easy to understand. If experimental efforts produce conclusive results to the extent that one stocking option definitely is superior to its alternatives, it may not be necessary to go beyond these primary analyses. In the event that these primary analyses are not conclusive there is a contingency built into the experimental design.

By now it likely is apparent that Wolverine Pond (intermediate size lake) has not been included in the primary analyses. In terms of experimental design, Wolverine Pond represents the "cross-over" point. Intuitive interpretation of results of stocking this intermediate size lake will provide insight into relative benefits of the four experimental factors since this is the only stocking location exposed to all four experimental affects. Actual analysis of data from Wolverine Pond stocking is much more difficult to explain in terms of experimental design and should be left to the professional statistician. For the present narrative it is sufficient to state that the experimental design for the Black Brook, Atlantic salmon enhancement project is an incomplete block design, and that analysis of this type of design is described by Kirk (1968).

Although the four experimental effects (i.e. non-consecutive fry stocking, consecutive fall-fingerling stocking, non-consecutive fall-fingerling stocking, consecutive fry stocking) require calculations similar to those described above, it should be evident that consecutive stocking sequences require many more repetitions of these calculations. For consecutive stocking sequences, the response variable that ultimately will be used in comparison of experimental effects will be calculated from the combined data sets. For such combined stocking analyses, appropriate sums will have to be calculated for the three year stocking sequences (total stocked) and resulting smolt production. Again, mean weights will be determined for each year class of juveniles stocked and for each smolt run. Average weight of total smolt escapement is calculated as:

> mean weight = ((mean weight of smolt from year 1 stocking x number of smolt from year 1 stocking) + (mean weight of smolt from year 2 stocking x number of smolt from year 2 stocking) + (mean weight of smolt from year 3 stocking x number of smolt from year 3 stocking)) / (number of smolt from year 1 + number of smolt from year 2 + number of smolt from year 3)

Relative to fall-fingerling stocking, it is the mean weight of the fry allocated to the rearing option (rearing channel, lake cage, etc) that is required for analysis and not the weight of the fall-fingerling released to the wild (although these latter data will be required for evaluation of effectiveness of fry feeding technologies).

Interpretation of Results

Having derived response variables (R = G - Z), we still are not in a position to make concise statements with regard to the relative efficiencies of the four experimental stocking techniques. In fact, assuming adherence to the stocking schedule outlined in Table 1.4, not until 1999 will sufficient data be available on which to base conclusions on experimental factors. On completion of the smolt run in 1999 (at which time the last Age 4 smolt from stocking cycle 2 will have emigrated from Gull Pond and from Micmac Lake) sufficient information will be available to compare experimental effects among the four primary stocking sites. These calculations are outlined in Table 1.5. Since most of these calculations are evident from Table 1.5, the only further explanation required is as follows:

- range = largest - smallest difference (i.e. ii less iii; Table 1.5)

- fk,n = constant as per Barnett (1960) factor K (i.e. 0.30, 0.35, 0.37, 0.38, 0.39, 0.40, 0.40)

- L = error calculation constant as per Barnett (1960) factor L (i.e. 1.96, 1.33, 1.09, 0.95, 0.85, 0.78, 0.72)

As examples of required data inputs, and anticipated results, three data sets have been simulated (all contrived to illustrate further considerations relative to evaluation of the experiments) and are presented in Tables 2.1, 2.2, and 2.4. Examples of analysis of response variables are presented in Tables 2.3 and 2.5. In these latter tables, the main decision criterion is whether the absolute value of the calculated effect is less than the absolute value of the error limit. For the contrived data, it is evident that Cycle 2 has failed to provide any indication that any one of the experimental effects has produced better results than any of the other effects. Such a result requires a decision as to whether the experiment should be continued according to the existing experimental design or whether the experimental factors should be changed (i.e. perhaps to investigate stocking density rather then the present factors). Continuation of the experiment could in fact identify that one effect is better than another. Consider Table 2.5. In this example, there has been considerable variability in the magnitude and direction of differences in experimental effects (as indicated by a significant interaction factor) and we are still no further ahead relative to the strict mathematical interpretation of our results.

Let Logic Prevail

Considerable effort has gone into contriving data sets that can not be interpreted in a strict mathematical sense. If the Evolutionary Operations analysis fails to identify that one experimental effect is better than another, then all effects are equally viable. This then would imply that the least costly enhancement technique, that would maintain salmon production on an annual basis, would be the most desirable in a social and economic context.

Relative to the present experimental design, this would mean annual fry stocking.

Whatever the result of the Evolutionary Operation analysis, economic comparisons ultimately will come into play. Relative to the examples presented (Tables 2.1, 2.2, and 2.4), one must consider the value of lost production (in a non-consecutive stocking strategy) as opposed to the costs of securing such production. Ultimately the decision, as to the most cost-effective salmon enhancement technology for application in Newfoundland and Labrador, will be based on social rather than strictly scientific principles. However, we are obliged to rely on the principles of experimental design to assure that appropriate decision criteria are available on which to base objective conclusions relative to desirable production options.

TABLE 2.1

BLACK BROOK SALMON ENHANCEMENT EXPERIMENT INPUT DATA

CYCLE	EFFECT	NUMBER OF FISH STOCKED				NUMBER OF SMOLT PRODUCED			
		YEAR 1	YEAR 2	YEAR 3	COMBINED	YEAR 1	YEAR 2	YEAR 3	COMBINED
1	Y1				789653				150034
	Y2	63257	61146	62292	186695	9488	7338	4672	21498
	Y3				139287				18759
	Y4	1167390	994385	1057370	3219140	256825	149157	116310	522292

BLACK BROOK SALMON ENHANCEMENT EXPERIMENT INPUT DATA

CYCLE	EFFECT	AVERAGE WEIGHT AT STOCKING				AVERAGE WEIGHT OF SMOLT PRODUCED			
		YEAR 1	YEAR 2	YEAR 3	COMBINED	YEAR 1	YEAR 2	YEAR 3	COMBINED
1	Y1				0.142				43.3
	Y2	0.159	0.138	0.141	0.146	42.6	36.5	39.8	39.9
	Y3				0.139				40.8
	Y4	0.136	0.155	0.147	0.145	45.2	38.7	37.6	41.7

CALCULATED INTERMEDIATE VARIABLES FOR
BLACK BROOK SALMON ENHANCEMENT EXPERIMENT INPUT DATA

CYCLE	EFFECT	G				Z			
		YEAR 1	YEAR 2	YEAR 3	COMBINED	YEAR 1	YEAR 2	YEAR 3	COMBINED
1	Y1				1.907				0.554
	Y2	1.864	1.859	1.881	1.870	0.632	0.707	0.863	0.721
	Y3				1.894				0.668
	Y4	1.935	1.840	1.848	1.986	0.505	0.632	0.736	0.606

RESPONSE VARIABLE (MEAN INSTANTANEOUS RATE OF CHANGE
IN POPULATION BIOMASS) FOR EXPERIMENTAL EFFECTS

	EXPERIMENTAL EFFECT			
CYCLE	Y1	Y2	Y3	Y4
1	1.3531	1.1495	1.2257	1.2795

Table 2.2

BLACK BROOK SALMON ENHANCEMENT EXPERIMENT INPUT DATA

CYCLE	EFFECT	NUMBER OF FISH STOCKED				NUMBER OF SMOLT PRODUCED			
		YEAR 1	YEAR 2	YEAR 3	COMBINED	YEAR 1	YEAR 2	YEAR 3	COMBINED
2	Y1				987653				99544
	Y2	138226	142555	140668	421449	24890	21383	16890	63143
	Y3				61558				12312
	Y4	787655	802577	799678	2389910	118148	80211	40027	238386

BLACK BROOK SALMON ENHANCEMENT EXPERIMENT INPUT DATA

CYCLE	EFFECT	AVERAGE WEIGHT AT STOCKING				AVERAGE WEIGHT OF SMOLT PRODUCED			
		YEAR 1	YEAR 2	YEAR 3	COMBINED	YEAR 1	YEAR 2	YEAR 3	COMBINED
2	Y1				0.150				54.6
	Y2	0.140	0.150	0.140	0.143	41.5	40.2	48.6	43.0
	Y3				0.160				98.3
	Y4	0.150	0.150	0.160	0.153	45.5	50.2	55.6	48.8

CALCULATED INTERMEDIATE VARIABLES FOR
BLACK BROOK SALMON ENHANCEMENT EXPERIMENT INPUT DATA

CYCLE	EFFECT	G				Z			
		YEAR 1	YEAR 2	YEAR 3	COMBINED	YEAR 1	YEAR 2	YEAR 3	COMBINED
2	Y1				1.969				0.7ee
	Y2	2.265	2.3ee	2.169	2.271	0.682	0.803	0.78e	0.75e
	Y3				2.306				0.677
	Y4	2.348	1.977	2.108	2.165	0.779	0.783	1.079	0.8ee

RESPONSE VARIABLE (MEAN INSTANTANEOUS RATE OF CHANGE IN POPULATION BIOMASS) FOR EXPERIMENTAL EFFECTS

	EXPERIMENTAL EFFECT			
CYCLE	Y1	Y2	Y3	Y4
1	1.3531	1.1495	1.2257	1.2795
2	1.2026	1.5148	1.6285	1.2988

Table 2.3

EVOLUTIONARY OPERATION WORK SHEET (FROM HICKS, 1966)
FOR BLACK BROOK, ATLANTIC SALMON STOCKING EXPERIMENT

Y1 = NON-CONSECUTIVE FRY STOCKING
Y2 = CONSECUTIVE STOCKING WITH FALL FINGERLINGS
Y3 = NON-CONSECUTIVE STOCKING WITH FALL FINGERLINGS
Y4 = CONSECUTIVE FRY STOCKING

CYCLE: N= 2

YEAR 1995

OPERATING CONDITIONS	1	2	3	4	STANDARD DEVIATION	
PREVIOUS CYCLE SUM	1.353	1.149	1.226	1.279	PREVIOUS SUMS	= 0
PREVIOUS CYCLE AVERAGE	1.353	1.149	1.226	1.279	PREVIOUS MEANS	= 0
NEW OBSERVATIONS	1.203	1.515	1.629	1.299	NEW S	= .165983
DIFFERENCES	0.150	-.365	-.403	-.019	RANGE	= .553278
NEW SUMS	2.556	2.664	2.854	2.578	NEW SUM	= .165983
NEW AVERAGES	1.278	1.332	1.427	1.289	NEW AVERAGE	= .165983

CALCULATION OF EFFECTS		ERROR LIMITS	
LIFE HISTORY EFFECT	.0961151	NEW AVERAGE	= .230041
STOCKING SEQUENCE EFFECT	-.0418513		
LHE X SSE =	-.0531075		

ANALYSIS HAS FAILED TO PROVIDE STATISTICAL EVIDENCE OF FACTOR SIGNIFICANCE.
EXPERIMENT REQUIRES FURTHER DATA IN SUPPORT OF DECISION CRITERIA

Table 2.4

BLACK BROOK SALMON ENHANCEMENT EXPERIMENT INPUT DATA

CYCLE	EFFECT	NUMBER OF FISH STOCKED				NUMBER OF SMOLT PRODUCED			
		YEAR 1	YEAR 2	YEAR 3	COMBINED	YEAR 1	YEAR 2	YEAR 3	COMBINED
3	Y1				826521				81503
	Y2	59877	59953	60375	180205	10777	8992	7245	27014
	Y3				141009				28202
	Y4	1000980	1001860	999856	3002690	150146	100555	50127	300828

BLACK BROOK SALMON ENHANCEMENT EXPERIMENT INPUT DATA

CYCLE	EFFECT	AVERAGE WEIGHT AT STOCKING				AVERAGE WEIGHT OF SMOLT PRODUCED			
		YEAR 1	YEAR 2	YEAR 3	COMBINED	YEAR 1	YEAR 2	YEAR 3	COMBINED
3	Y1				0.150				54.7
	Y2	0.160	0.150	0.160	0.157	41.7	39.8	47.2	42.5
	Y3				0.150				37.9
	Y4	0.150	0.150	0.160	0.153	45.2	50.1	55.5	49.1

CALCULATED INTERMEDIATE VARIABLES FOR
BLACK BROOK SALMON ENHANCEMENT EXPERIMENT INPUT DATA

CYCLE	EFFECT	G				Z			
		YEAR 1	YEAR 2	YEAR 3	COMBINED	YEAR 1	YEAR 2	YEAR 3	COMBINED
3	Y1				2.037				0.800
	Y2	2.398	2.185	1.964	2.192	0.736	0.743	0.732	0.742
	Y3				2.335				0.679
	Y4	2.410	2.147	2.015	2.245	0.801	0.849	1.031	0.895

RESPONSE VARIABLE (MEAN INSTANTANEOUS RATE OF CHANGE
IN POPULATION BIOMASS) FOR EXPERIMENTAL EFFECTS

	EXPERIMENTAL EFFECT			
CYCLE	Y1	Y2	Y3	Y4
1	1.3531	1.1495	1.2257	1.2795
2	1.2026	1.5148	1.6285	1.2988
3	1.2371	1.4499	1.6559	1.3496

Table 2.5

EVOLUTIONARY OPERATION WORK SHEET (FROM HICKS, 1966)
FOR BLACK BROOK, ATLANTIC SALMON STOCKING EXPERIMENT

Y1 = NON-CONSECUTIVE FRY STOCKING
Y2 = CONSECUTIVE STOCKING WITH FALL FINGERLINGS
Y3 = NON-CONSECUTIVE STOCKING WITH FALL FINGERLINGS
Y4 = CONSECUTIVE FRY STOCKING

CYCLE: N= 3

YEAR 2001

OPERATING CONDITIONS	1	2	3	4	STANDARD DEVIATION	
PREVIOUS CYCLE SUM	2.556	2.664	2.854	2.578	PREVIOUS SUMS	= .165983
PREVIOUS CYCLE AVERAGE	1.278	1.332	1.427	1.289	PREVIOUS MEANS	= .165983
NEW OBSERVATIONS	1.237	1.450	1.656	1.350	NEW S	= .0943387
DIFFERENCES	0.041	-.118	-.229	-.060	RANGE	= .269539
NEW SUMS	3.793	4.114	4.510	3.928	NEW SUM	= .260322
NEW AVERAGES	1.264	1.371	1.503	1.309	NEW AVERAGE	= .130161

CALCULATION OF EFFECTS		ERROR LIMITS	
LIFE HISTORY EFFECT	.150592 *	NEW AVERAGE	= .0724404
STOCKING SEQUENCE EFFECT	-.043493		
LHE X SSE =	-.0884769 *		

FACTOR INTERACTIONS ARE SIGNIFICANT, EVOP ANALYSIS IS OBSCURE